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<p>GRASS is a geographic information system (GIS) software package containing a variety of programs to perform and display geographic analysis and digital image processing.</p> <p>This report familiarizes users with the GRASS analytical tools and shows how to use the tools to help solve resource management problems.</p>					
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FOREWORD

This work was completed for the U.S. Army Engineering and Housing Support Center's (USAEHSC) Natural and Cultural Resources Division under the Facilities Engineering Application Program Work Unit F79, entitled "GRASS Implementation," Task 2. The work was performed by Central Washington University (CWU), Ellensburg, WA, 98926, under Contract DACA88-87-D-007 with the U.S. Army Construction Engineering Research Laboratory (USACERL). The contract was monitored by USACERL's Environmental Division (EN). Dr. R. K. Jain is Chief of USACERL-EN. The USAEHSC Technical Monitor was Ms. Jamie Clark.

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Table of Contents

PREFACE	1
Chapter 1: PROBLEM SOLVING WITH GRASS	5
Stages in a GRASS analysis	8
Chapter 2: PROBLEM SITUATIONS: MONOLAYER APPLICATIONS	13
Camp Rushmore, South Dakota	15
Situation No. 1: Isolating an Area for Analysis	18
Situation No. 2: Defining Zones	21
Situation No. 3: Producing Tabular Information	24
Situation No. 4: Cleaning up a Satellite Image	29
Situation No. 5: Excluding Unsuitable Areas	32
Chapter 3: MULTILAYER TOOLS	35
weight	35
combine	37
Gmapcalc	40
Pmap	47
Chapter 4: PROBLEM SITUATIONS II: MULTILAYER APPLICATIONS	54
Situation No. 6: Predicting Forest Fire Potential	55
Situation No. 7: Screening Data for Selected Characteristics	58
Situation No. 8: Mapping Potential Occurrence of an Endangered Species	63
Situation No. 9: Mapping Potential Occurrence of Archaeological Sites	66
APPENDICES	A.1
Appendix 1: Spearfish, South Dakota Permanent Map Layers	A.2
Appendix 2: Short Descriptions of Archaeological Sites in the Spearfish, South Dakota Area	A.9
Appendix 3: Keystroke Guide to Procedures: Problems 1 Through 6	A.19

PREFACE

GRASS is a geographic information system (GIS) software package containing a variety of programs to perform and display geographical analysis and digital image processing. These programs are often referred to as "tools" and the GRASS package as a "toolbox." As with many tools, some of the GRASS programs perform similar functions. Thus, when you are trying to solve a problem with GRASS, there are a variety of permissible methods using different tools in different order. It is important that you learn the strengths and limitations of each of the many tools to use them most effectively.

GRASS analyses can help you anticipate and assess the environmental impacts of training exercises, determine the best locations for encampments, or locate terrain that is appropriate for employing different weapons systems. And you can use GRASS map development tools to produce specialized maps based on your own data or on data extracted from other geographic information sources.

In preparing this manual, we have had to assume some things about you. First, whether military or civilian, you are facing the prospect of using GRASS to solve real operational problems on a military post or other government installation. Second, you were probably educated in the natural sciences or engineering, but you are not an expert in cartography or remote sensing. And third, even though you are not an experienced GRASS user, you are familiar with the basic UNIX® operating system commands and procedures, and you understand basic statistical concepts.

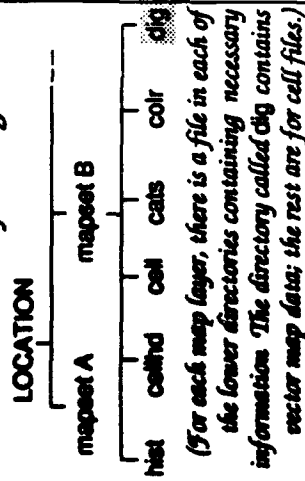
PREFACE

The Geographic Resource Analysis Support System (GRASS) is a fast, accurate, highly interactive map analysis and manipulation toolkit that will enable you to see spatial relationships among diverse geographical phenomena.

What we have assumed about you.

2 The GRASS Problem-Solving Manual

A bit more about GRASS - Maps are stored in the file structure in the following manner:



Although GRASS has both a menu-driven interface and a command-line interface, this manual will use only the latter. You enter the command-line mode by running "GRASS3" after logging in on your system; the menu version is entered by running "grass3."

What this manual tries to do.

Like all GISs, GRASS uses maps as the medium of analysis. Most of the data that the system uses are stored and displayed as maps. Maps representing the same geographic area are stored in the same *data base*. Individual maps (such as those containing data on elevation, soil types, vegetation, etc.) are called *map layers*. In a GRASS analysis, you see the interrelationships between or among map layers. For example, you might use GRASS to juxtapose a map layer that shows types of vegetation with a map layer that shows classes of slopes to develop a slope stability map, or as part of a fire hazard analysis. For this reason, it is important that you learn to visualize the various map layers in your data base (as well as those that you can create using various GRASS tools).

To get you started, we have provided a series of increasingly complex situations similar to those you might encounter as a land manager on a military installation. We are confident that as you follow through our approaches to these situations, you will begin to conceptualize and solve your own, unique land management problems.

This is not just a book of recipes; our approaches are not intended as procedures you must follow to achieve certain kinds of results. Rather, we intend to show you what utensils you have to work with and what happens when you combine certain ingredients in certain ways. We ask you to follow along in preparing a few representative "dishes." The best cooks, however, like the best GRASS users, are those who understand principles and use recipes as guidelines that they can adjust and combine to meet new situations.

Our intentions are to:

- 1) Familiarize you with the GRASS analytical tools.

- 2) Show you how you might use them to help solve resource management problems,
- 3) Teach you how to conceptualize problems so that you can apply GRASS tools effectively,
- 4) Point out minor problems you might encounter while using the GRASS toolbox and show you how to deal with them, and
- 5) Supplement (not replace) the GRASS User's Reference Manual, which provides basic documentation for all the commands and excellent tutorials for some of the more complex tools.

Chapter 1 provides an overview of GRASS as a resource management tool and develops a four-stage problem-solving process based on questions you should ask as you proceed with any GRASS analysis.

Chapter 2 first examines some of the GRASS analytical tools that are used with only one map layer at a time (monolayer tools). We then offer a set of interrelated instructional problems based on situations like those that commonly occur on lands managed by various federal agencies, especially the military. In each of these situations, we guide you through the problem-solving process.

Chapter 3 starts by examining the three most frequently used multilayer analytical tools and the most developed of the hard copy output programs in GRASS.

An Overview of Tool Types

*There are several classes of GRASS tools in addition to the monolayer and multilayer types. Those with names that are all in lower case letters (**display**, **weight**, **combine**, etc.) are interactive tools. Those beginning with upper case letters (**Gmapcalc**, **Dcell**, **Dwhat**, **Pmap**, etc.) are command-line tools, and those beginning with a lower case letter and a 'dot' (**d.colors**, etc.) are partially interactive.*

4 The GRASS Problem-Solving Manual

Chapter 4 presents a second, more complex set of instructional problems. In this set our analyses are not as definitive because we expect you to be developing problem-solving strategies of your own by this point.

We have tried to anticipate your needs in the design of this manual. The outside margin of each page contains comments, hints, and warnings that will help you to better understand concepts and procedures.

You will notice that we have used typographic differentiation to set off some elements of the text. **Boldface Roman** type signifies GRASS commands. Map layer names are in **boldface sans-serif**.

We have also tried to include plenty of maps and thumb-nail graphics to help you visualize and interpret results of your analyses. These are only approximations of what you will see on your monitors because we made them on an Apple Macintosh. Actual map layer graphics would have been much easier to produce in GRASS, but publication limitations made the use of color impractical.

The three Appendices to the manual contain, respectively, a listing of the map layer categories in the Spearfish data base that is included with all releases of GRASS, the list of archeological site information that accompanies the data base, and a keystroke-by-keystroke listing of the solutions to manual problems 1 through 6.

PROBLEM SOLVING WITH GRASS

GRASS (Geographic Resources Analysis Support System) can be a tremendous aid to land management. GRASS software complements field work and standard cartographic techniques by allowing you to filter, manipulate, and analyze spatial information rapidly and accurately.

GRASS can help you to manage resources because it enables you to use many forms of data, in varying scales, in an analysis. GRASS can read data tapes such as U. S. Geological Survey or Defense Mapping Agency Digital Elevation Models (DEMs), LANDSAT or SPOT satellite images, and data from other GISs. It can also convert digitized data from hard copy maps, or other sources such as aerial photos, to same-scale digital form.

GRASS can rapidly screen information on multiple map layers to define locations that have specific, and often complex, combinations of geographic characteristics. This analytical capability, coupled with modeling programs like **Gcost** or **Gsurface** can help you define locations where problems might occur owing to some given set of circumstances.

GRASS may change your perception of some environmental condition by showing you a connection that you had not previously considered. For example, a GRASS analysis conjoining known erosion sites and slope may indicate that serious erosion occurs on less steep gradients than you thought and lead you to look at the relationship of aspect (the direction in which the slope is facing).

Chapter One

In using GRASS, you have to know what you want the resultant maps to look like — in your mind — and then employ the appropriate tools to generate them.

Modeling programs can do a lot of thinking for you, but you have to understand what they are doing or you will have difficulty interpreting and assessing the accuracy of the results. The GRASS toolkit allows you to do both arithmetic and logical manipulations of gridded cell value data.

Because they have such a wide range of tools available, different operators will probably produce slightly different results... depending on the choices that they make.

Results of a GIS analysis should never be a surprise!

GRASS neither interprets circumstances nor defines problems. **Gcost**, for example, will not tell you the actual cost of doing or locating something at a given location. It will provide you with a relative idea of the difficulty of undertaking some activity at one location rather than another and perhaps help you estimate the magnitude of problems that might be encountered.

GRASS will not do many things that cannot be done using logic, mylar, and colored pencils. But, it can do them faster, more accurately, and with greater detail at varying scales than you could with manual cartographic techniques. GRASS can quickly develop a series of maps, based on a single input map, by reclassifying data categories, making logical (Boolean) overlays, and doing weighted overlay analyses. It can perform proximity analyses, cross tabulation of coincidence between data themes, and arithmetic and logical manipulations of category values on individual map layers.

But, problem-solving with GRASS is not a matter of simply plugging information into preconceived formulas. Because each land management situation is unique, the most effective way to use GRASS is to apply a four-stage set of procedures to every situation:

1. **Define** the problem,
2. **Acquire** the necessary data,
3. **Manipulate** the data, and
4. **Generate** hard copy maps and tabular reports.

As you follow us through the situation analyses that form the core of this manual, you will see this process at work. In practice this process is seldom linear. That is, you will seldom completely define a problem, then acquire all the information you need, then perform all the necessary manipulations, and

then generate the perfect map or report. You will often find the stages looping back upon themselves. Unavailability of information, for example, may require that you redefine the problem, or a given manipulation may require that you gather more information. You may even seem to be in more than one stage simultaneously. But keep in mind that looking back at an earlier stage will often help you to solve problems you may be experiencing at a later stage of analysis.

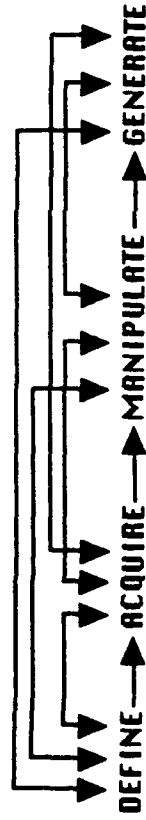


Fig. 1.1. An analysis in GRASS, or any other GIS, consists of a number of feedback loops that require the analyst to think ahead and refer back to other stages of the process.

Because GRASS can produce so many variables in so many different ways, the same analyses done by different people might vary slightly in their results. Therefore, it is best to attack analyses as a team rather than as individual analysts. To achieve consistent, reliable results, an environmental management team should agree from the beginning on the nature of the data it will use in a given analysis and on the nature of an acceptable outcome.

GIS analysis is a highly recursive process!

Stages in a GRASS Analysis

GRASS analyses can provide valuable support for your environmental and resource decisions if you follow a simple, four-stage plan of action. The following sequential questions should help guide you through these stages.

Stage 1: DEFINE the problem

1. What is the nature of the problem to be solved?

Determine desired outputs, the intended audience, and the unique characteristics of your site.

2. What data are necessary to analyze and solve the problem?

What map layers will I need to use for solving this problem?

3. What information must I include in my final map?

Obviously, the final map must show a solution to the problem, but it must also make that solution understandable. If the situation asks that you define an area suitable for tank maneuvers, for example, then that area must be represented on the map with enough landmarks to make it geographically recognizable.

At this point you should begin to visualize what your final map will look like. You should also begin to consider analytical paths that will lead to the map you envision.

4. What information should I include to make my final map clear and useful for my audience?

The information that ought to be included depends upon your audience. Title, location, scale, and legend are necessary information and may be enough for you to understand a solution, but audiences who do not work with maps every day may need geographical reference points and other supplemental data. For example, some people can get their bearings by looking at road networks, while others need to know where installation boundaries or nearby settlements are located. A grid system may give an instant recognition of scale for some, but may get in the way for others. Adding place names and commentary, might clarify a complicated map for an audience that understands information best in written form.

5. Do I need a tabular report, and what information should it include?

You need a tabular report if the problem requires quantitative analysis: the acreage that a particular project will cover, for example, or the number and size of discrete sites that are both 50 feet from roads and 100 feet from water. Many problems require such analyses to support the graphic results. Once you have decided to do a tabular analysis, you should then consider what information the results should include and how the results should be measured (you would not present an analysis of a small archaeological site in terms of square miles, for example).

Stage 2: ACQUIRE the necessary data.

6. What information do I need to produce the desired result?

A well developed GRASS data base provides you with a vast array of spatial information to sort through. You often have to create map layers that the data base does not contain. For example, later in this manual, you are asked to solve a problem in which the locations of an endangered species of plant are necessary to the solution. In this scenario, you are not given the locations of the sites. Instead, you must determine likely locations based on the combination of habitat factors that would be most likely to support the plant's growth.

10 The GRASS Problem-Solving Manual

Mapsheets commonly contain map layers that have been derived from the standard data base map layers for purposes specific to a particular project.

7. What information is available to me?

The obvious first place to look is in the data base. For most GRASS sites there will just be one data base that will contain all the standard map layers. There will also be a number unique *mapsets* that have been developed for other projects. These often contain map layers that are useful in other analyses.

If the data base does not contain all the information you need, you can import information from external sources, such as hard copy maps, magnetic tapes, and quantitative analyses, through a variety of processes. They can also be incorporated in your analyses as background information that is not entered into GRASS (as when you use such information as the basis for reclassifying the categories of a map. Such sources are useful, for example, in verifying ground truth (how accurately a map coincides with the area it represents).

8. What intermediate maps do I need?

An intermediate map contains data that you need in your final analysis but are not available as primary layers in your data base. GRASS tools let you produce new maps that contain the information that you need. Intermediate maps may be a single map layer or they may be created by combining data from two or more map layers. You might need to simplify an existing map by filtering out extraneous data. For example, a soils map might contain twenty or more soil types, while you are only interested in two of the types; or an elevation map from a DEM may have too many categories for your specific purposes. Or perhaps a map does not contain enough information. For example, you might need to define 50-meter riparian corridors along stream courses, or identify 100-meter corridors along a road.

More often, the information on two or more map layers may be needed in a single map that you can work with more efficiently. For example, you may need to create a map that shows only forest types that exist within the boundaries of your management area.

Stage 3: MANIPULATE the data.

9. What procedures do I use to produce intermediate maps?

GRASS has two major classes of tools: one allows you to work with only one map layer at a time; the other allows you to work with several map layers simultaneously. For convenience, we refer to these as *monolayer* and *multilayer* tools. Many of the tools, either monolayer or multilayer, can produce similar results. For example, if you wanted to work with areas containing only certain soil types, you could **mask** out soil types that you were not interested in, or, using **reclass**, you could create a new class of soils comprised of those in which you were interested. Either approach might give you precisely the map you need. As you gain experience with the system, the results generated by particular tools will become more predictable, and it will be easier to pick just the right tool for any particular job.

The multilayer tools allow you to manipulate categories on two or more maps at a time, in a variety of ways. They can also make a monolayer manipulation unnecessary. For example, certain types of vegetation might exist only on particular types of soils. You could use the multilayer tool **combine** to make a logical composite of the **soils** and **vegcover** map layers instead of using the monolayer tool **reclass** to isolate these types of soils.

You may have to generate intermediate maps in order to generate other intermediate maps. Making a flow chart that shows the different intermediate maps you will need in a complex analysis is usually well worth your time.

10. What procedures should I use to produce the final analysis?

In the final analysis you will draw upon the same tools and procedures as you did to create intermediate maps to create a single graphic image of a solution. When you see this image on the monitor, ask yourself if it looks like what you visualized in the beginning. If it does not, think through your analysis again

Monolayer	Multilayer
GRAPHIC	
mask	weight
reclass	combine
distance	Gcross
neighbors	Ginfer
Gmfilter	basins.fill
clump	
TABULAR	
Gsurface	Gmapcalc
watershed	Gdrain
Gios	Gcost
report	coin
cell.stats	Gstats
Gstats	

Fig. 1.2. Tool types and modes of operation in GRASS. The tools listed here are only a sampling of the total range available. Those in the shaded boxes are tools with modeling, or statistical analysis capabilities. Most all of the multilayer tools will operate on single maplayers as well.

12 The GRASS Problem-Solving Manual

GIS analysis is a highly recursive process!

to see where you might have gone wrong. If everything seems to be in good logical order, then you probably created a mistaken mental image for yourself. Chances are good, though, that you were right the first time. After all, you asked all the right questions.

Stage 4: GENERATE maps and tabular reports.

11. What procedures can I use to produce a final report?

With your solution on the monitor, your next step may be to create a tabular report to support it. Since you have already chosen the data to be included in your graphic analysis, the tabular analysis should be easy. Here you can employ tools like **report**, **cell.stats** and **coin** to prepare the data.

At this point you may think that you are done, but you must finally produce a presentable map. The map that you have on the screen is only the raw graphic representation of the analysis without the necessary supplemental data, which may include such things as a vector image of the road network, a UTM grid, a scale, or place name labels.

In preparing the map to be printed, you can change the color scheme either interactively in **display** (or **d.colors**) or in **support** where you can directly modify the color table or update the legend with descriptions of what each color means. You may then wish to add cell data, such as towns, to the map using a multilayer tool like the **overlay** function of **combine**.

Using either the interactive **p-map** tool, or the much more powerful **Pmap** program, you can now print the solution map, using a variety of options to include such things as grid and vector overlays.

Chapter Two

PROBLEM SITUATIONS:

MONOLAYER APPLICATIONS

The GRASS monolayer tools allow you to analyze and manipulate information in single map layers and to print tabular reports as well as graphic images. You will generally use monolayer tools in conjunction with multilayer tools. Monolayer tools can solve some simple problems; however you will most often use them to create intermediate map products. Among other things, monolayer tools will let you:

1. zoom-in on a map to get a better look at a particular feature or isolate an area,
2. eliminate unnecessary clutter (noise) from a map to sharpen its appearance and emphasize important elements,
3. extract information from existing map layers by means of various mathematical manipulations, or
4. generate reports in either graphic or tabular form.

Although there are many tools from which to choose—and we must refer you to the *GRASS User's Reference Manual* for descriptions of most—we will briefly consider those tools you will use in the problem situations that follow.

Use **window** to control the size of the geographic area you are working with. You can limit your view, and analysis, to any rectangular area on a map. You can also change the effective scale by making the area larger or smaller. Once you set coordinates in **window**, they remain constant until you change them, so get into the habit of changing the window back to the default coordinates (full data base window) after an analysis is completed.

14 The GRASS Problem-Solving Manual

Most GRASS analytical tools are designed to work with cell files; that is, they work with raster data. Sometimes, both raster and vector versions of a map are stored in a GRASS data base. The vector versions are used for overlaying linear data such as roads and streams on cell files. When using the analytical tools, run them on the raster file versions.

Several monolayer tools can eliminate extraneous or unnecessary information from a map. You may want to **mask** out all but a small part of the data base, because you only need to work in that area or because working in a limited area will speed up an analysis. Any manipulation done on any map in your data base will only be done on the area within the mask. A mask remains in place until you remove or rename it and should be removed when an analysis is finished.

Another way to **generalize** a map (to remove unwanted detail) is with **reclass**, which allows you to rearrange (reclassify) the categories of information a map contains, or to lump several separate categories into one. You can also **reclassify** all the categories surrounding an area of interest to some constant value, such as 1 or 0, and create a map that looks similar to one you might create with **mask**. The difference is that **reclass** does not prevent analyses from being done on the areas that were reclassified to zero (areas outside your area of interest).

The tool **neighbors** can reduce unwanted data complexity. It is a digital filter that can sharpen hard-to-read maps (such as satellite images) by generalizing, or simply changing, the information they contain. A square moving filter matrix of 3x3, 4x4, 5x5, 7x7 (etc.) cells passes over a map layer, analyzes the values of the cells within the matrix, changes the value of the center cell according to your specification, and then puts that value into a new map layer. It assists you in bringing out patterns on the map that may be significant, while reducing the presence of information that is irrelevant to your analysis.

In addition to controlling the geographic extent of an analysis and manipulating the information contained in a map layer, monolayer tools can **add** information to map layers. The tool used most often for this is **distance**, which creates zonal boundaries at specified distances from particular categories, sets

of categories, or linear features. For example, you might use **distance** to indicate a buffer zone along a stream, or a corridor along a road.

Some monolayer tools generate tabular or graphic reports of analyses. To retrieve tabular information about a particular map layer, use **report** or **cell.stats**. Both of these provide area statistics for map layer categories, but **report** also lists the total area for each category in percent coverage and square kilometers. To produce hard copy maps, you must use either **print**, which is interactive, or **Pmap**, which is command-driven. We will discuss **Pmap** along with the multilayer tools in the next chapter.

On the following pages you will be presented with a series of problem situations to be analyzed and solved using GRASS tools. For each situation, you should refer to the questions posed in Chapter 1, "Problem-Solving with GRASS," as you select the tools and techniques to do the job.

All of the problem situations in this manual are centered around Camp Rushmore, South Dakota, which lies entirely within the Spearfish data base that is distributed with the GRASS software package. Categories for the Spearfish data layers are listed in Appendix A. Camp Rushmore is a fictitious military post, but its problems are representative of what might be encountered on any military installation.

Camp Rushmore, South Dakota

Camp Rushmore, South Dakota, was founded in early 1875, following General George A. Custer's first forays into the Black Hills. Originally, it was to be an outpost for keeping an eye on a small band of Black Hills Sioux who were

If Camp Rushmore existed, this would be its history.

16 The GRASS Problem-Solving Manual

threatening revolt. It was located near what became the town of Spearfish to keep the Indians from raiding the settlement. Its initial land allocation was only a quarter section, 160 acres. During the Black Hills gold rush that began in 1875, the garrison tried to control both Indians and miners. Diaries and daily reports also indicate that the garrison's commander had his hands full keeping the troops from joining the prospectors.

Things quieted down in the 1890s because many of the Sioux either died from introduced diseases or migrated to Canada. The gold fields remained bolsterous, but most of the good lodes had been found. Overland wagon roads passed largely to the south of the Black Hills, across Kansas and Nebraska, and the frontier soon passed the camp by.

Long, harsh winters made this north slope of the Black Hills an undesirable place on which to spend a tour of duty, and Camp Rushmore became a backwater post, sometimes used for disciplinary assignments. Its maximum garrison size during the Indian wars was never larger than one company of mounted cavalry, with support personnel. During the 1890s, the camp narrowly escaped being turned into a reservation for some of the more belligerent bands of *Peu Haut-arc* (Poohawk) Indians.

*To learn more about environmental conditions on Camp Rushmore, consult your data base. The **Delide.show** command will display all the data base layers in your mapset in alphabetical order. The **list** command will let you take a quicker look at map layer names and titles.*

It was nearly fifty years before the camp had a fresh burst of activity. During World War II, Camp Rushmore became a training center for elite combat units because of its remote location and because its terrain, climate, and vegetation bore so many similarities to those of the Eiffel and other hilly areas of north central Europe. It was a particularly good spot for training Nordic ski troops in woodland combat.

In 1943, an additional 13,000 acres was purchased or transferred from other federal agencies, which brought the post up to its present size. Once peace was restored and demobilization begun in 1945-46, some of this land was leased out to civilian farmers and livestock graziers, some of whom had sold it to the government several years before.

Threatened with closure many times during its nearly 125-year history, it has hung on. But sometime in the 1990s its luck will probably run out. It has been included on the Special Commission's list of bases to be closed unless a new use can be found for it.

Camp Rushmore is the site for the representative problem situations that we present on the following pages. The first series of problems can be solved using GRASS monolayer tools, while subsequent problems require that you use both monolayer and multilayer tools. We stress that there is often more than one way to solve a particular problem; to illustrate this, we will sometimes present alternative strategies.

Some of the map layers you will create in solving the problems in the monolayer series will be useful in working through the problems posed in the multilayer series (Ch. 4). So, if you have room on your system, save the files you create until you have finished this manual. If you choose not to do the less complex, monolayer problems, at least read through them.

Situation No. 1: Isolating an Area For Analysis

Capt. Patrulla, Officer-in-Charge of Camp Rushmore's military police, has been ordered to establish patrol routes over all roads within the boundaries of the camp. He has heard that your GIS can generate all kinds of maps, so he has come to you looking for something simple on which to display the routes.

Definition

Your job is easy: all you need is a map of the camp that shows the roads within its boundaries. Since there is no need to show the relative position of the camp, you can make a map that fills the display screen. Capt. Patrulla has also asked you to show only the area inside the camp because he wants to reinforce his concern that everything outside its boundaries is off limits.

Acquisition

A quick scan of your **PERMANENT** mapset shows that you have a vector file entitled **roads**. But you have no map called **Camp Rushmore**. There is, however, a file named **trn.sites** which shows the different training areas on the post (see marginal note on next page). Since Camp Rushmore is made up entirely of these training sites, you know that a map which combines all the training areas into a single area will comprise a map of the whole camp.

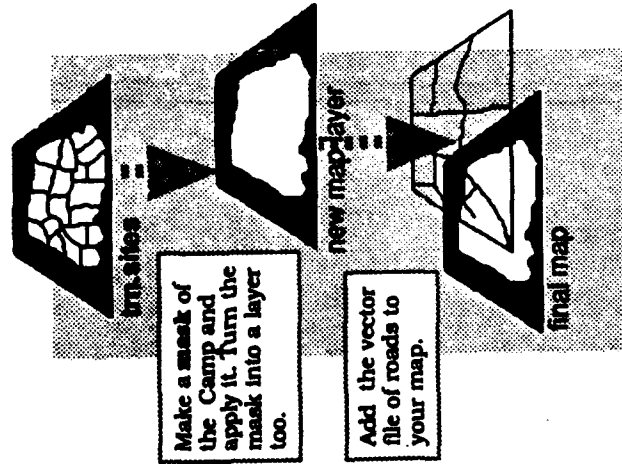


Fig. 2.1. Conceptual flow chart of procedures for the analysis of Situation No. 1. Note that this, and the flow charts for the following problems, do not lay out solutions to the problems, but rather the ways in which you should try to frame your analyses.

The tool called **mask** will enable you to isolate the area you want (the camp); **reclass** will allow you to define all areas within the mask as a single category, deleting borderlines between the various training sites that comprise Camp Rushmore. Either tool will allow you to create an intermediate map on which you can overlay the **roads** vector map.

- 1a. Use **mask** to produce a mask that includes all categories except 0 from the **trn.sites** map layer. Name it **rushmore** by using **Gcopy** and the command,

Gcopy cell MASK rushmore

to create your mask.

- 1b. Or, use **Gmapcalc** (of which more later) to make your mask with the command string,

Gmapcalc MASK = trn.sites / trn.sites

- 1c. Or, use **reclass** to make a map layer of the camp by reclassifying all 18 non-zero categories of **trn.sites** to 1. Name this new map layer **rushmore**. This is slower than the two previous options, but because **reclass** is an interactive tool, it is conceptually more direct

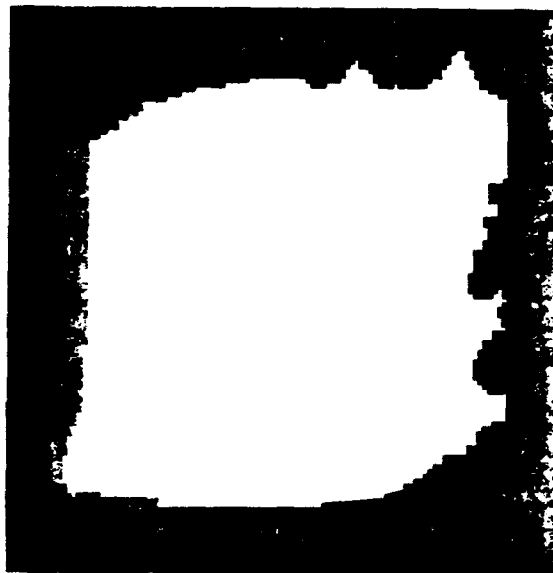


Fig. 2.2. The outline (boundaries) of Camp Rushmore. As either a map layer or a mask, you can name it **rushmore**.

*Note: when you superimpose the data base vector image of **trn.sites** onto the cell image, you may find that an area at the northwest and another at the southeast corner of the camp is not shown on the cell map. These are cantonment areas. You may have to label these areas on the vector file, using **digit**, and then make a new cell file from the modified vector image, if you wish to include the cantonments as part of the final map. We have.*

You can simply **reclass** the entire map, as in step 1c., but any mask you set will apply to all subsequent map layers, allowing you to eliminate all information outside your area of interest (Camp Rushmore) in one step.

*Note, too, that a mask is essentially just another map layer, but has the special property of screening out information on map layers on which it is overlaid. The **mask** program and a **MASK** created with **Gmapcalc** work the same way; but **MASK** becomes the name of the mask, whereas **mask** allows you give it any name you wish.*

You also have a cell file named roads, but overlaying two cell files requires you to use a more complex, multilayer tool. Vector maplayers produce much smoother lines than cell (raster) files. You can easily convert a vector file to a cell file in GRASS. Going from cell to vector is more difficult. Vector files cannot currently be used for purposes of analysis, just for display. Since this situation doesn't require a tabular report, which you can only obtain from a cell file, the use of the vector file is appropriate.

Warning: mask remains in place until you remove it. Since you are saving the new map, rushmore, we advise that you remove the mask here. Simply type: "Gremove cell MASK".

and may be the simplest of the three with which to work if you are just starting out with GRASS.

2. Use **display**, or **Dvect**, to display the roads vector file with the mask in place. If you use **Dvect** (or **display**), the roads outside the post will appear in the masked-out area on the screen display, but **paint** will let you eliminate them in the final hard copy map; **paint** asks you if you wish to use the current mask.

Generation

3. Use **paint** to print out a hard copy map for Capt. Patrulla.

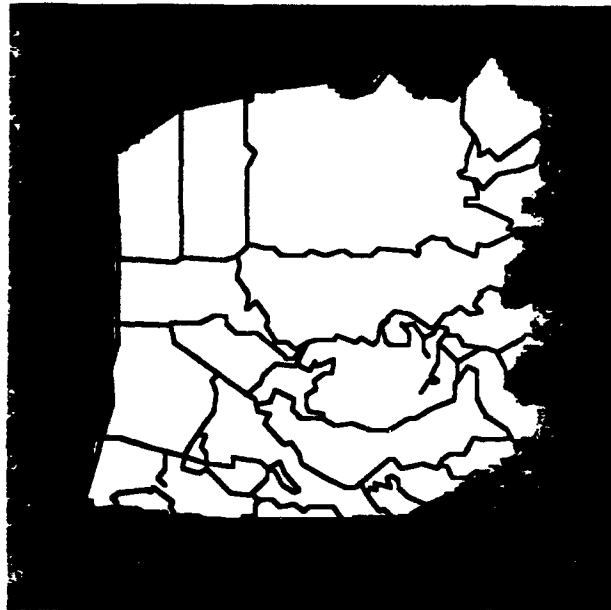
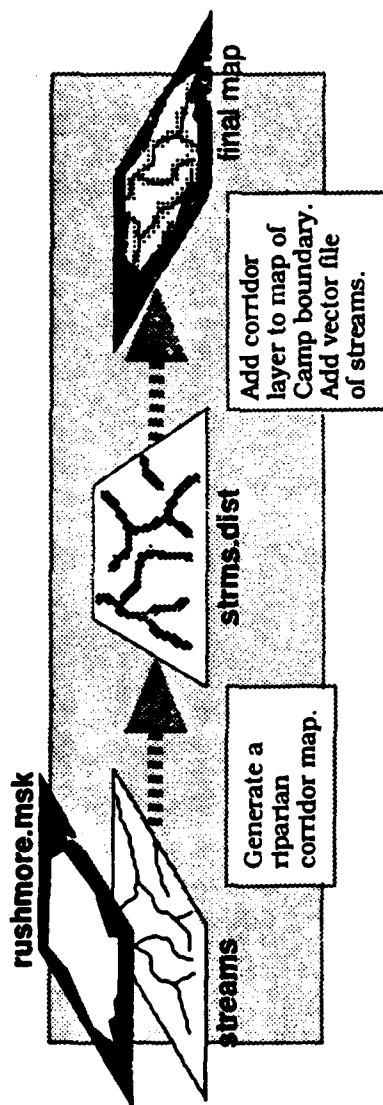


Fig. 2.3. Camp Rushmore's road network. Your map should look approximately like this.

Situation No. 2: Defining Zones

Last summer's reserve training maneuvers severely damaged sections of Camp Rushmore's riparian zones. You are going to recommend that only minimal activity be conducted in these ecologically sensitive areas for the next year. You are preparing a briefing for Col. Jones, the Camp Commandant, and want to produce a map showing all riparian zones on the installation.



Conceptual flow chart of procedures for solving Situation No. 2.

Definition

Normally a riparian zone in this region averages 100 meters on each side of a stream course. For your purposes this is probably a sufficient buffer zone; however, in consideration of past damage, you also want to indicate a zone 100 meters wide outside that buffer that is to be used only for foot traffic. So, all you need for this map is to show the area of the camp, its stream network, and the two buffer zones.

22 The GRASS Problem-Solving Manual

Acquisition

In this situation you will use the cell file named **streams** along with the map **rushmore** that you created in Situation No. 1.

Manipulation

Here you want to isolate the Camp Rushmore area just as you did in Situation No. 1. Create a **mask** of the camp again to eliminate stream courses that lie outside the camp. Running the GRASS tool **distance** on the **streams** cell file will create the two buffer zones you need.

1. Recreate the **mask** of Camp Rushmore (**rushmore**) that you created in Situation No. 1.
2. Now, if you are unfamiliar with the **streams** cell file, **display** it to find out what categories correspond to the streams within the masked area. Use the **h**(highlight) function to help you. If you are already familiar with the layer, you will know that the streams within the mask are all category 2.
3. Use **distance** to create a 100 meter zone (one cell wide) and a 200 meter zone (two cells wide) along category 2 streams (because a zone extending 100 meters beyond a 100 meter zone is actually a 200 meter zone). Name this new map layer **strms.dist**.
4. **Dcell strms.dist** to display what you have created.

Generation

Use **paint** to print out a hard copy of **streams.dist** and you are ready for your briefing.

*Here you want to use the cell file of **streams** rather than the vector file, because you cannot use vector files in an analysis. You will also need to use the corridor generating tool called **distance**.*

*Other tools you can use to help you identify categories on map layers are **cell.stats**, **describe**, **Dwhat**, and the highlight function of **d.colors** (in conjunction with **Dcell**).*

Remember to remove the mask after you have finished the problem.

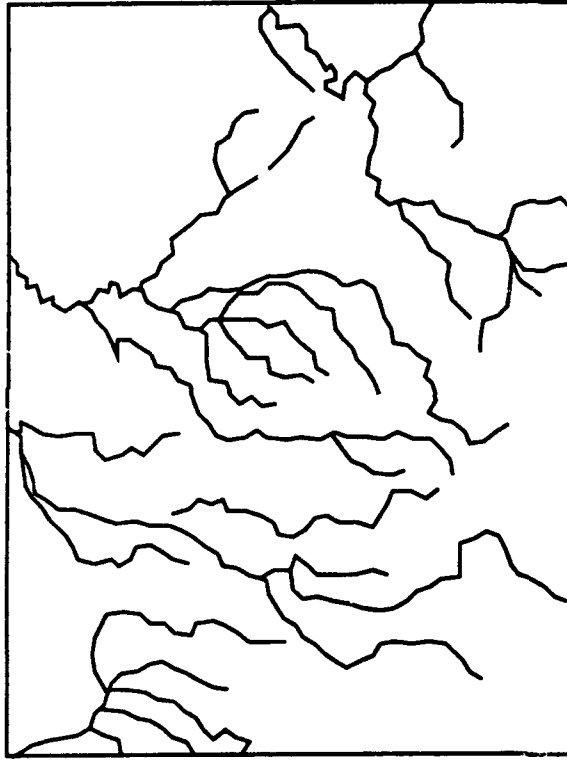


Fig. 2.4. The streams vector file looks approximately like this.

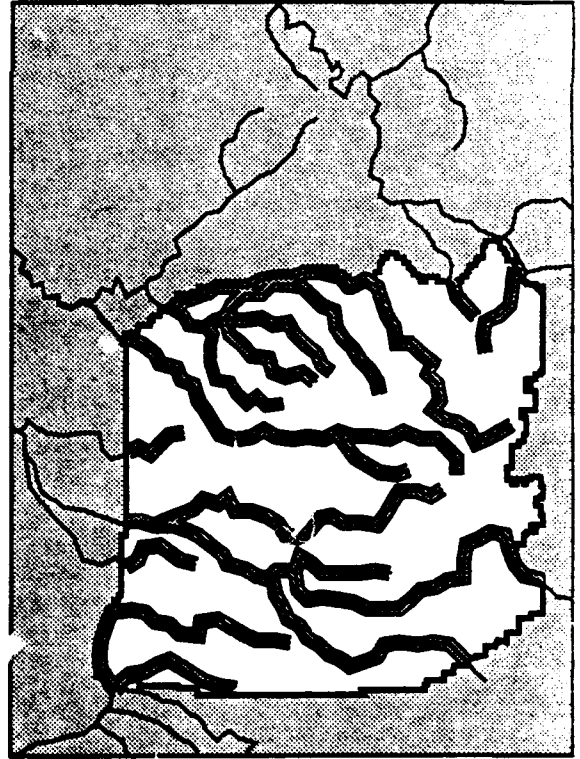


Fig. 2.5. The finished riparian buffer zone map will look like this if you **paint** the vector file over the cell file without the mask being set. With the mask, streams stop at the camp boundary.

Situation No. 3: Producing Tabular Information

Often, seemingly unrelated events chain together into major situations. For example, a species of woodpecker that eats primarily Rocky Mountain Pine Beetle larvae is on the endangered species list. The beetles are a problem in Black Hills forests and the woodpeckers have been known to nest within the boundaries of the post—in fact, they like to nest near their major source of grubs. It is relatively certain that tanks moving through their nesting habitat during the spring would upset nesting pairs and certainly reduce brood success. This would almost certainly worsen beetle infestations. But the camp is being considered as a possible site for mechanized ground troop maneuvers that require wooded terrain. The exercise is estimated to require a minimum of 10,000 acres, at least half of which should be wooded. Is there enough wooded land within the Camp to allow the training exercise to be carried out without disturbing the woodpeckers?

Definition

Ultimately, all you need here are some numbers: (i.e., a simple tabular report). But, you can't get to the numbers without creating at least a couple of maps. So, even though you won't necessarily print it, you must think in terms of a "final" map. This map must include all wooded areas within the camp and show which wooded areas have been infested by Rocky Mountain Pine Beetles.

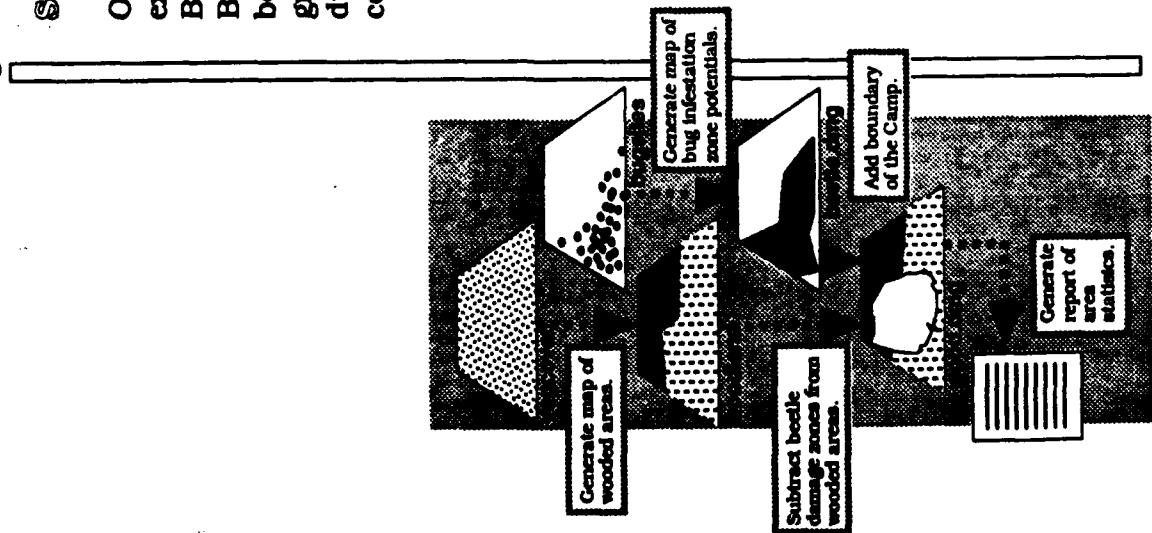


Fig. 2.7. Conceptual flow chart for determining woodlands that have been afflicted with Rocky Mountain Pine Beetle infestations.

Acquisition

Again you will use the map **rushmore** to define your area of concern. The **vegcover** layer provides you with information on different kinds of vegetation, including forests. And **bugsites** will show where the Rocky Mountain Pine Beetles have attacked the forest. But, the information on which the **bugsites** cell map was based is ten years out of date, so you will need to update it.

Manipulation

Set your **mask** of the post boundary from **rushmore**. **Vegcover** contains three forest categories. Use **reclass** to group them into a single category. **Bugsites** shows the areas of Rocky Mountain Pine Beetle infestation that existed about ten years ago. Assume that the beetles disperse their infestations fairly uniformly, at a rate of 30-50 meters per year. You can then use **distance** to generate probable current infestation zones.

Using **Gmapcalc** to subtract the zones of infestation from the woodlands area, creates a map on which to run **cellstats** to find the total forest acreage that is not infested.



Fig. 2.8. The wood-land map layer.

1. Reestablish your Camp Rushmore mask.
2. Reclass categories 3, 4, and 5 of **vegcover** to category 1 and set all other categories to 0. Name the new map layer **woodland**.
3. Run **distance** on **bugsites** to create a 500-meter zone around the bug infestation sites and name the new map layer **beetle.zones**.

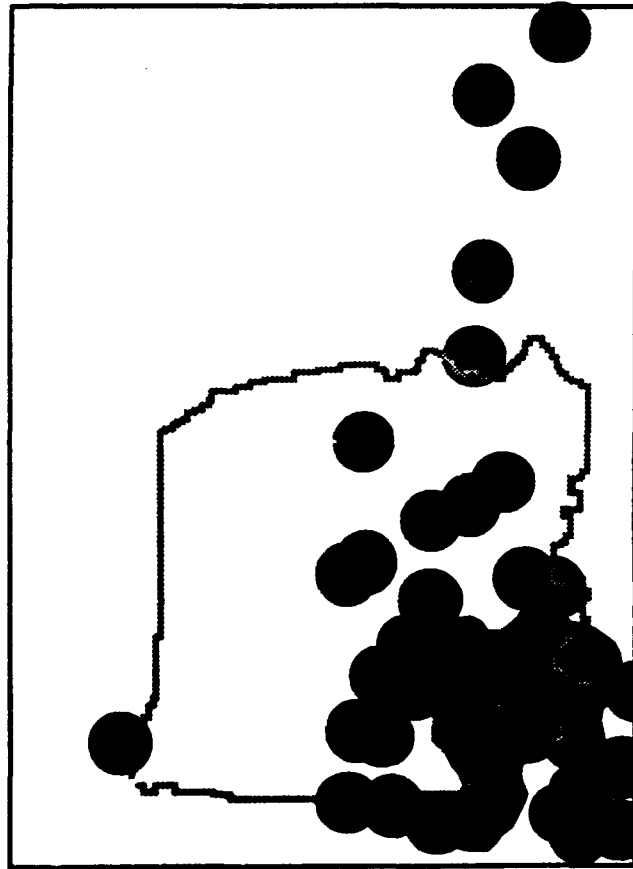


Fig. 2.9. beetle.dmg, shown within the entire data base window. The Camp Rushmore boundary is included for orientation.

4a. Drop areas of **beetle.dmg** out from woodland using **Gmapcalc**, and name the new map layer **wood.dmg**. The **Gmapcalc** command lines to use are:

Gmapcalc beetle.dmg = 'if (beetle.zones -1, 0, 1, 0)'

Gmapcalc wood.dmg = 'if (beetle.dmg * woodland, woodland - beetle.dmg, woodland).'

*These **Gmapcalc** commands may not make sense at first, but they work. The first says, "if (cells in) beetle.*

zones, when you subtract 1, do not equal 0, then make those cells equal 1. Make all others 0."

The second string says: "if

***beetle.dmg** times woodland does not equal 0, then subtract **beetle.dmg** from woodland, else (otherwise) use the cell value from woodland."*

Alternatively, you could skip the **Gmapcalc** step and get an answer by using **cell.stats**.

- 4b. Use **cell.stats** on **woodland** to find total forest acreage [Category 1 (Wooded areas) = 16,839.87 acres].
5. Use **cell.stats** on **beetle.dmg** to determine the total forest acreage infested by beetles [Category 1 (RMPB Damage) = 5,819.20 acres].

Generation

If you use the first method (**Gmapcalc**), run **cell.stats** on **wood.dmg** to find the total area of woodland that is probably not infested with Rocky Mountain Pine Beetles, and can thus be assumed to not contain woodpecker nesting sites.



Fig. 2.10. woodland with the areas of **beetle.dmg dropped out using **Gmapcalc**. The Camp Rushmore boundary is superimposed for clarity. Areas outside the boundary would, of course, be masked out in your analysis.**

If you choose the second method, subtract acreage determined in step 5 (beetle infestation in wooded areas) from the results of step 4b (wooded areas). The result is 11,020.67 acres, which means that you can probably endorse the maneuvers (which only require 5,000 acres). Note, however, that this method tells you nothing about the contiguity of the wooded zone.

Fig. 2.11. The tabular report produced by cell.stats. The line with the information you are seeking is shaded.

Layer:	[wood.dmg] in mapset [johnr]				
Title:	If (beetle.dmg * woodland, woodland - beetle.dmg, woodland)				
Mask:	<rushmore> in mapset <johnr>				
Window:	north:	4928000.00	east:	6090000.00	
	south:	4914000.00	west:	5900000.00	
	res:	100.00	res:	100.00	
Category	Acres		Hectares	Sq. mi	
0	no data	54567.00	22083.00	85.26	
1		11167.31	4517.00	17.47	
total		65728.60	26600.00	102.70	

Situation No. 4: Cleaning up a Satellite Image

You have in the Spearfish database a LANDSAT image of your area. Even though it has been enhanced to clarify some features, it still has a "fuzzy" look because of the interspersed of widely different reflectance values. Although you can see the information that it contains, others have trouble interpreting it. Because you would like to use it more effectively in reports, you need to clean it up; that is, produce an image in which the predominant cell values are emphasized in order to make the larger patterns of surface configuration more visible.

The problem you face here is one of *filtering* the values of the individual cells in your LANDSAT image in order to smooth it. You will try to create a more uniform gradation between values, or remove discrepant values. Any such filtration of the image will reduce its overall information content, because that is an unavoidable result of generalization. So, although the resultant map layer will contain less signal (information), it will also contain less noise. This is not necessarily undesirable, however. Sometimes simpler is better. Furthermore, since the image has already been resampled to 100-meter resolution from its original 65- x 80-meter resolution, you probably won't lose too much specific detail, and will probably be better able to see patterns that might be important.

Acquisition

Since this is simply a manipulation of the LANDSAT cell composite file, you will only need the map layer entitled `mss.image`.

Communications theorists like to talk about the signal/noise ratio. In cartography, this is simply an index of the amount of useful information an image, map, or text contains.

If you had started with an enhanced Thematic Mapper image at its original 30x30 meter resolution, you might be a little more hesitant to smooth out the gradations between values. Once the resolution is coarsened, fine discrimination of detail on that image cannot be restored.

Manipulation

The problem is solved easily using the GRASS tool called **neighbors**. The most important decision you must make is which of the six filtration strategies you will use to achieve your desired result. Three things you have to consider are:

1. How many categories the map layer has.
2. How much average difference between adjacent cell values there is, and
3. The size of the filter matrix that you will use.

Your choices of neighborhood analysis (filtration) strategies are:

- [1] mode (most frequently occurring value in neighborhood)
- [2] minimum (lowest value in neighborhood)
- [3] maximum (highest value in neighborhood)
- [4] average (rounded arithmetic mean of values in neighborhood)
- [5] diversity (number of different categories in neighborhood)
- [6] interspersion (number of categories in neighborhood different from category of the center cell)

See the GRASS User's Reference Manual for clarification of these strategies.

You need to experiment with this tool, but a good place to start is with [4]. With GRASS you can try different options very rapidly to see which gives the best result. But be careful how you define "best." Option [1] will give the results you seek in this case, because it best preserves existing visual patterns. Options [5] and [6] will give valid results, but not the simplification you want. The other choices will simply obscure the data too much.

Generation

Once you have the image clarified to your satisfaction on the graphics monitor, **paint** a copy at an appropriate scale. The results will be considerably more edifying than the image on the following page because you have the great advantage of seeing it in color.

Once again, Gmapscale offers an alternative method which, although it is more complicated, allows you to more precisely control the results of your smoothing operation. It is described by Mark Johnson in "Grass Clippings," the GRASS newsletter (Spring 1988; Vol. 2, No. 2, page 9).

Fig. 2.11. mss. image before
smoothing with neighbors.



Fig. 2.12. mss. image
after smoothing with
neighbors.



Situation No. 5: Excluding Unsuitable Areas

The National Weather Service has predicted an unusually dry summer. The Chief Medical Officer, Brig. Gen. Sierrahuesos, says dust-borne diseases like *coccidioidomycosis* (Valley Fever) could be a problem during forthcoming summer exercises. Base trainers are planning a summer training exercise in parts of areas 3, 4, 5, 6, 7, 8, and 9. They have decided to take precautionary measures by not allowing field encampments within 100 meters of unpaved roads. To prevent stream pollution, you have decided to exclude areas lying within 200 meters of streams.

Definition

This problem requires you to combine two zonal maps: one of stream corridors and one of unpaved road corridors. The twist is that the area in which you are interested is *outside* these corridors. Therefore the map must show the boundaries of the seven training areas and the areas suitable for field encampments. The latter can be enhanced by showing the actual courses of the streams and the routes of the roads with vector images. If you can distinguish between the two types of line, their intersections should be clearly visible too.

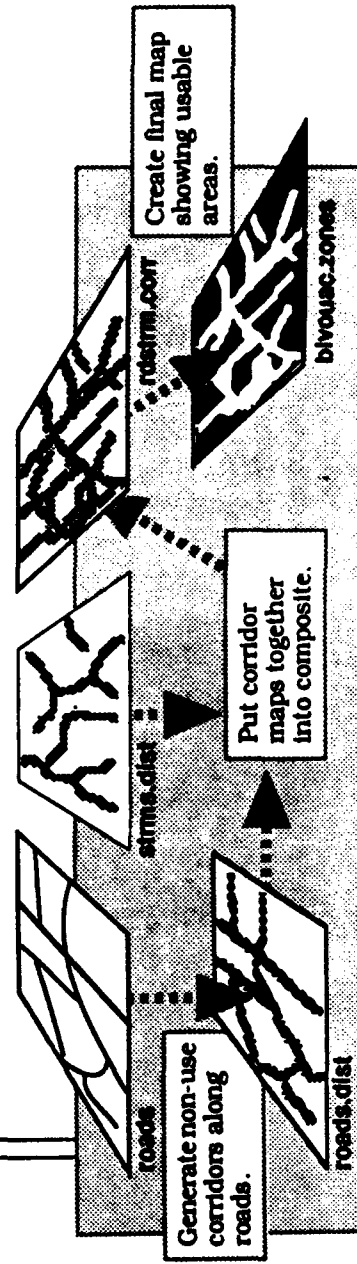


Fig. 2.13. Conceptual flow chart for the area exclusion problem.

Acquisition

You only need three maps for this problem. The one entitled **trn.sites** will be used to create a **mask**. You have already created a map layer named **strms.dist** (which contains a 200-meter buffer zone along streams) in Situation No. 2. And the other map layer you need is **roads**.

Manipulation

Set a **mask** to include training areas 3 through 9 of **trn.sites**. Run **distance** on **roads** to create a 100-meter zone along dirt roads. From this, and **strms.dist**, you need to create a map in which the two sets of areas outside the buffer zones become a single category. So, use **reclass** to change all categories to 0, except for the highest, which will be 1. This will give you binary images in which the corridors have a value of 0 and the areas outside the corridors have a value of 1.

The most direct way to put these maps together is with the tool known as **combine**, but we haven't gotten to that yet. So, use **Gmapcalc** on your two new maps to add the road and stream corridors together into a single map layer showing suitable areas for bivouacs.

1. Set **mask** from **trn.sites**.
2. Run **distance** on **roads** to create the 100-meter corridors; name this map **rds.dist**.
3. Run **distance** on **streams** to create the 100-meter corridors; name this map **strms.dist**.
4. Use **Gmapcalc** on **rds.dist** and **strms.dist** to add them together. The following **Gmapcalc** command lines should do the job:


```
Gmapcalc corridors = 'if (strms.dist == 1 || rds.dist == 1)'
      [creates binary map layer of corridors]
      Gmapcalc encamp.zones = abs (corridors - 1)
      [turns areas between corridors into category 1]
```

As you begin to create more new maplayers in your database, it's a good idea to develop some system for naming them, so you can remember what they are later — without having to look. Use of extensions like .r or .dist or .rgh is helpful in this regard.

*When you add the map layers together, the areas where the non-corridors intersect have a value of 2. Where they do not, the value is 1. The corridors themselves are, of course, 0. The next step reduces values of 2 to 1 and 0 by stating, in effect, that "if the value of **rdstrm.corr** is 2, then make it 1; set everything else to 0." The result is a binary map.*

*If you would like to get a bit more detailed, on a copy of **tm.sites**, reclass the seven training areas to zero.*

*Then use **patch** or*

Gpatch to plug **encamp.zones** into the modified **tm.sites** layer.

Then paint the new map with roads and streams vector overlays.

Generation

Use **paint** to print a hard copy map of **encamp.zones**. Overlay the vector files of **tm.sites**, **streams**, and **roads** to assist map users in orienting themselves.

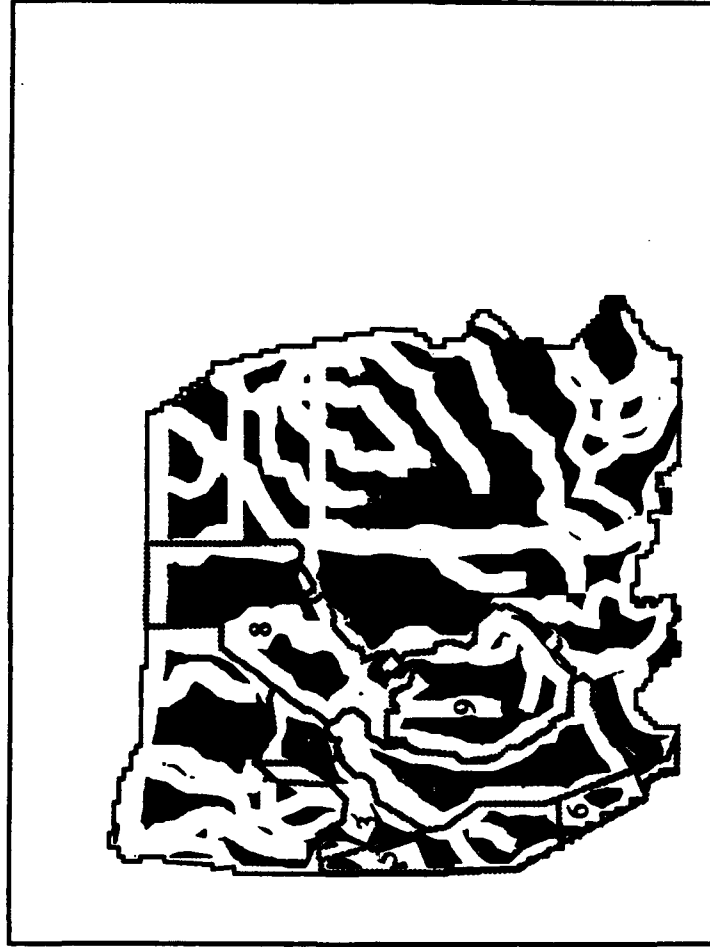


Fig. 2.14. The map **encamp.zones**. Here only the boundaries of the seven-training areas are shown owing to the small scale. Your map will be more complete.

MULTILAYER TOOLS

So far we have concentrated on getting you used to solving problems with the monolayer tools in GRASS. The next series of problem situations (Ch. 4) will require that you use the multilayer tools that comprise the analytical core of the system: **weight**, **combine**, and **Gmapcalc**, along with the powerful map design and printing program, **Pmap**.

Details of the tools' operation, and tutorials on their use, are available in the *GRASS User's Reference Manual*. However, we thought you might appreciate a few helpful hints as you begin to familiarize yourself with them.

weight

This is an analytical tool that allows you to make *relative* comparisons of data from two or more map layers at one time. In **weight** you can assign relative values to different categories of information from different map layers, and you can then analyze the relative values of combinations of categories on a single map layer. You can use **weight** on single map layers, instead of **reclass** or **Greclass**, and get the same results by assigning the same values to all categories that you want to represent in a single category.

Conducting a meaningful weighted composite analysis requires that you be well acquainted with the ground truth of the map layers you use, as well as with the ways that different types of geographic phenomena interact. You also have to assess, for each particular analytical situation, which map layers to include and the relative importance of the different kinds of categories they represent. For example, in a given situation it might be profitable to consider whether slope has any relevance at all to the problem, or if elevation is more or less important than aspect or depth-to-bedrock.

Chapter Three

On page 11 we presented the following illustration. We thought it might be helpful to you to see it again here.

Monolayer	Multilayer
GRAPHIC	
mask	weight
reclass	combine
distance	Gcross
neighbors	Glafer
Gmfilter	basins.fill
clump	
Gsurface	Gmapcalc
watershed	Gdrain
Glos	Gcost
TABULAR	
report	cola
cellstats	Gstats
Gstats	

*In point of fact, **weight** is just an application-like interface that combines **reclass** and **Gmapcalc**.*

Steps in weight Analysis

1. The most important element in using **weight** is a clear sense of the relative importance of the various map layer categories used in the analysis. You should also have a pretty good idea what the final map should look like because, without that, you may not recognize a misleading result.
2. Choose the map layers you wish to use:

choose layerA layerB layerC . . .

Layer A, layer B are simply the names of existing maps in your database.

3. **Assign** appropriate weights to the categories that are important to your analysis:

assign layerA <cats1> <val>
assign layerA <cats2> <val>
assign layerA <cats3> <val>
assign (layerB) <cats> <val>

4. To check your selections and assignments, type: **list analysis**. This will give you a listing of all of the map layers, categories, and weights that you have assigned.
5. Once you are satisfied with the weightings you have selected, you should **save**. You will be asked what name you wish to give to the analysis.
6. Next, you need to decide whether to do your analysis by **adding** or **multiplying** the values you have **assigned**. Each method has advantages, and disadvantages. Try running it both ways to see what happens. You may need to go back and assign new values to make it come out right.

*Or you can simply type in:
assign (layerA)
to enter an interactive
environment that looks more like
reclass.*

*Keep in mind that any number
multiplied by 0 equals 0. Adding a
0 to a number simply leaves it un-
changed.*

7. After saving your analysis, run it with the `execute` command. The **weight** program will tell you the minimum and maximum possible values that your analysis will produce, as well as the maximum number of categories. It also asks if you will accept that number of categories. If you don't want that many, you can enter a smaller figure and **weight** will try to normalize the category values across that number.

combine

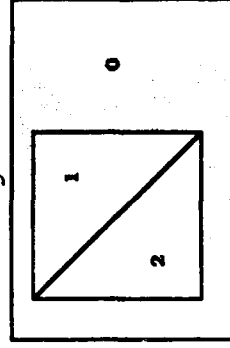
This analytical tool allows you to compare and filter data from two or more map layers at one time. You can perform logical (Boolean) analyses involving intersection (**and**), union (**or**), and exclusion (**not**) of selected areas. The results of intersection and union analyses always emerge as binary (two-valued) maps, which can then be further combined with other intermediate maps, used as a mask, or used as an overlay. The overlay features (**over** and **cover**) of **combine** add to its versatility in making comparisons. Both types of overlay result in maps having multiple categories, but the categories of interest are highlighted differently. The **over** command creates a map in which categories from one map layer are superimposed on a second map transparently, so the **as** on the first map show through. The **cover** command creates an opaque overlay that hides the categories on the first map which lie beneath it.

Consult your GRASS User's Reference Manual for a list of **combine**'s commands. Single categories or sets of categories, for example, can be extracted from an existing map layer using the **group** command, either for display or for analysis. Map layers you create in **combine** may be saved in your personal mapset.

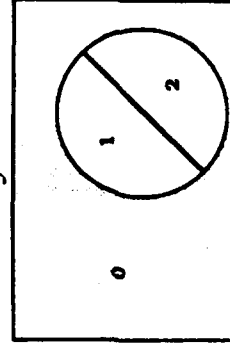
As with most GRASS tools, the key to using **combine** is trying to visualize the map that will result from an analysis.

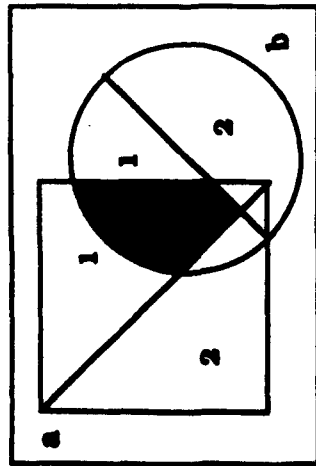
*On the following page are several diagrams illustrating **combine** commands. They are based on the two simple 'map layers' below.*

Layer A

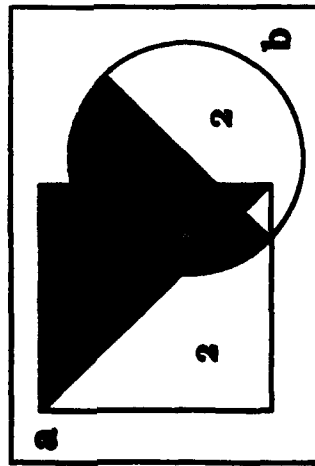


Layer B

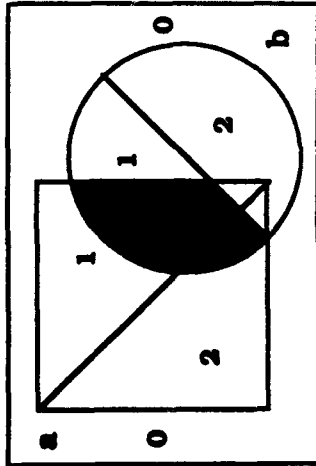




(and(group 1(a))(group 1(b)))



(or(group 1(a))(group 1(b)))



(and(not(group 0(a)))(group 1(b)))

Command Syntax: Commands for any operation you wish to perform in **combine** must be enclosed in parentheses. The parentheses in any command string must be balanced; there must be as many right parentheses as left. A syntactically and logically valid command is termed a "(Map Expr)."

The following are all valid command strings:

- [1] (group 3-5 (vegcover))
- [2] (and (group 2-4 (vegcover)) (group 3-7 (geology)))
- [3] (or (not (group 0 (streams)))(group 3-12 (soils)))
- [4] (cover landuse (group 7-14 (soils)))

(Note that in the **over** and **cover** operations, the name of the map layer on which the overlay is to be made is **not** enclosed in parentheses.)

- [5] (over landuse 4 (group 3 (vegcover)))

Here the 4 following landuse refers to the color that is to be used for the transparent overlay. In this case, you have specified gray. See the section on A Note on the Color Logic of combine (below) for further information.

- [6] (name <mapname> (over landuse 4 (group 3 (vegcover))))

Each time you enter a valid (Map Expr), **combine** runs an analysis. When you create a useful image and **name** it (in order to save it), the program will re-run the analysis. To do this, you would normally retype the (Map Expr), including [name] and your map layer name for the resultant map ahead of the rest of the string as in [5] and [6]. Fortunately there is an easier way. If you wanted to save analysis [5] above as "mymap," you would simply type:

(name mymap (expr 5))

This will save the analysis to your mapset, under the name **mymap**. Notice that here, again, the name of the map on which you wish to perform an operation is not enclosed in parentheses.

Fig. 3.1 Venn diagrams showing the different areas that can be isolated with the three different Boolean operators in **combine**.

A Note on the Color Logic of **combine**:

You will discover that, no matter what color scheme you had on any given map layer, when you bring it to the screen in **combine**, the pattern of colors always looks like this:

- | | |
|-------------------------|--|
| 1 Red | 6 Green [yellow + blue] |
| 2 Yellow | 7 White [red + yellow + blue (additive mode)] |
| 3 Orange [red + yellow] | 8 Gray [red + yellow + blue (subtractive mode)] |
| 4 Blue | 9+ Various tertiary colors (primaries and secondaries with added gray) |
| 5 Purple [red + blue] | |

When you specify the color in **over**, the program adds the value of that color (1 for red, 2 for yellow, 4 blue, etc.)* to the value of any cell on the overlaid layer that coincides with categories you are overlaying. Since **over** produces a transparent overlay, this incrementing can help you identify the area of the overlay, but some combinations of color values can lead to confusing results. Try running overlay analyses using the same command string but with different colors.

When you request that a transparent overlay be done in gray, it shows up on the image as a kind of grayish film on top of the underlying polygons of the overlaid categories. All things considered, this seems to be the most useful color selection for visual interpretation of an **over** analysis. The best thing to remember in using **over** is to keep it simple; don't drop complex overlays on top of complex map layers. Plan the colors that will result from an overlay analysis so that they will enhance significant distinctions.

*Note: Aliases (shorthand expressions) for all of **combine**'s commands exist within GRASS. Once you have mastered the use of the commands, consider using some of the shorter forms (see Manual).*

** To ask for these colors in a command string you use 1, 2, 3, or 4; but when the program does its thing, it adds the value of the color in the **combine** color scheme.*

*At this point you are ready to solo in **combine**. It's important to keep trying to visualize what the maps resulting from your analyses ought to look like. One trick to assist you in this is to use the multi-window display screen capabilities of GRASS. Check the Manual entries under **Dnew** and **Dchoose** for details.*

Gmapcalc

This is the Swiss army knife of GRASS, which you began to use in the mono-layer problem series. **Gmapcalc** allows you to manipulate data in ways that are either more difficult, less direct, or impossible in other routines.

Gmapcalc works on whole map layers. If you want to work on less than an entire map layer, you may either: 1) set a mask, 2) zoom to a smaller window, 3) create an intermediate map layer before running **Gmapcalc**, or 4) use the many arithmetic and logical functions of **Gmapcalc** to limit the range of category values on which you wish to perform an operation.

Not only can you use more than one map layer in a **Gmapcalc** equation, **Gmapcalc** allows you to perform both arithmetic and logical operations within a single equation. Arithmetic manipulations tend to preserve or increase the number of categories on your resultant map. Logical manipulations will not.

As explained in the *GRASS User's Reference Manual*, all **Gmapcalc** equations take the form:

result = expression.

Result is always the name of the new map layer that you wish to create. The expression may be as complex as you wish. It is always a good idea to use parentheses () or brackets [] to group the elements of your expression statement into their proper algebraic order of precedence.

Some Examples of Gmapcalc Equations

MAPCALC> soils.reclass = soils.reclass

will turn a **reclassified** map into a regular cell map, such as is required by the **neighbors** program.

Note: In all the following Gmapcalc expressions the "MAPCALC>" portion is the application prompt to which you must respond with a valid equation.

One very useful application of **Gmapcalc** is to multiply, or divide, the category values of a map layer by a constant. For example, there are 3.28 feet in one meter. If you wish to convert a digital elevation model (DEM) in meters to one in feet, the following equation will do it:

```
MAPCALC> elev.ft = round (elevation * 3.28)
```

The round function rounds the results of a multiplication to the integer values necessary for creation of a legitimate cell file. Values will be truncated, if you do not specify rounding.

```
MAPCALC> strmdist.bin = (strm.dist - 3)/(strm.dist - 3),
```

will turn the database map layer **strm.dist**, which consists of three non-zero categories, into a binary layer in which categories 0, 1, and 2 each become 1, and category 3, the area outside the corridors, becomes 0 ($0 - 3 = -3$; $1 - 3 = 2$; $2 - 3 = -1$; and $3 - 3 = 0$). Dividing a map layer by itself, of course, turns all non-zero values to 1, while all 0 values remain 0. This is a quick and easy way to create a binary map from any multi-category map, but the subtraction is not necessary in most cases.

An alternative equation which accomplishes nearly the same thing by creating a mask of the stream corridors is:

```
MAPCALC> MASK = abs (strm.dist - 3).
```

Like the previous equation, this one subtracts 3 from each value of **strm.dist**. Here, however, the function **abs** returns positive integer values—regardless of sign—and creates a mask which acts just like a binary map layer when invoked. The following diagrams illustrate the arithmetic operators in **Gmapcalc**.

You may use the name of an already existing map layer (in your own mapset) if you want to overwrite it with the results of a new equation.

*Before it tries to perform any calculation on a map layer, **Gmapcalc** attempts to parse the expression that you have entered. If it can't, it tells you so, and then waits for you to give it something that it can parse.*

*Note that this equation does not create a binary layer. The **mask** tool just treats it like a binary.*

c	2	3	3	2	3
	2	4	4	3	2
	1	1	4	3	2
	3	3	3	4	3
	1	2	4	3	3

=

a	0	1	1	1	2
	1	2	2	2	1
	0	0	2	1	1
	0	0	0	2	1
	0	1	1	1	1

+

b	2	2	2	1	1
	1	2	2	1	1
	1	1	2	2	1
	3	3	3	2	2
	1	1	3	2	2

MAPCALC> c=a+b

c	-2	-1	-1	0	1
	0	0	0	1	0
	-1	-1	0	-1	0
	-3	-3	-3	0	-1
	-1	0	-2	-1	-1

=

a	0	1	1	1	2
	1	2	2	2	1
	0	0	2	1	1
	0	0	0	2	1
	0	1	1	1	1

-

b	2	2	2	1	1
	1	2	2	1	1
	1	1	2	2	1
	3	3	3	2	2
	1	1	3	2	2

MAPCALC> c=a-b

Fig. 3.2. Numerical matrices illustrating the operation of the arithmetic operators in **Gmapcalc**. In each case the two on the right are processed to yield the values in the matrix on the left.

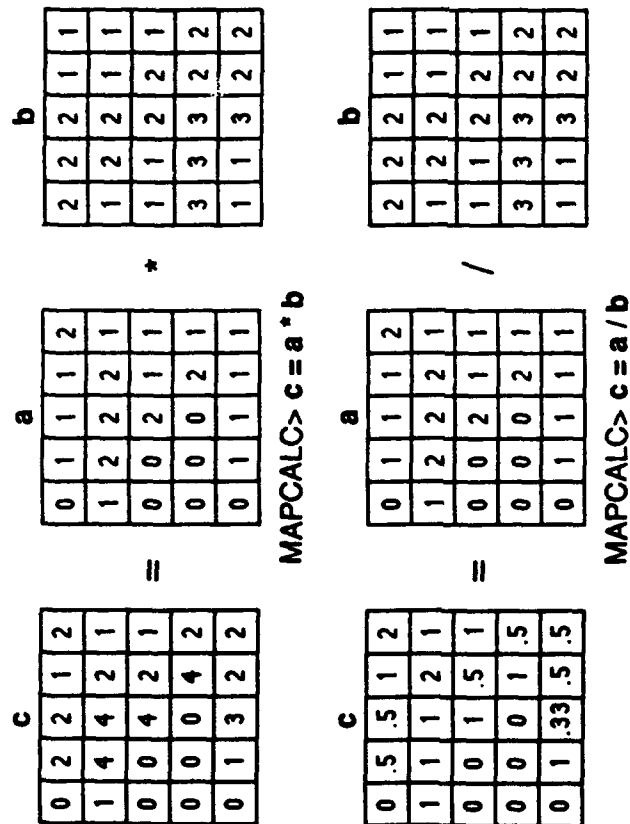


Fig. 3.2 (continued). Note that in the last example **Gmapcalc** would truncate or round the result of the calculation before filling each cell, unless you specify a floating point result [as in: **c = float (a/b)**].

The arithmetic and logical operators of **Gmapcalc** are straightforward and should be easily understood. Perhaps less easy to fathom are some of the fifteen *functions* that are available. The functions can be included at any point in an equation, but you must be careful to separate functions and their associated variables in algebraic form with appropriately placed parentheses. The following discussion should be helpful in using the functions of **Gmapcalc**.

But, as always, please consult the *GRASS User's Reference Manual* for the formal discussion of commands.

Gmapcalc's "if" operator is difficult to understand until you have used it a few times. Its basic form is `if(x)`. When this is applied in a calculation, all non-zero cell values will be converted to a value of 1. Zero (0) values remain at zero, as in:

```
MAPCALC> map1 = if (roads).
```

If we put this expression in plain English, it would read, "If a cell in **roads** is not equal to 0, then give it a value of 1 in the map layer **map1**." Every "if" statement has an expressed or implied "then," as well as an implied "else" ("if this, then that, else zero").

In the form `if(x,a)`, all specified cell values of 'x' will be converted to the value you specify at 'a,' as in:

```
MAPCALC> woodland = if ((vegcover >= 3) && (vegcover != 6), 1).
```

This should be read: "If the **vegcover** category value is greater than or equal to 3, and not equal to six, then give it a value of 1, otherwise (else) give it a value of zero; put these values in new cell file called **woodland**."

There are two further variations of the if function, but the key to understanding them is to remember that if the first condition is true, then **Gmapcalc** is to complete the second, third, and/or fourth condition.

Thus, in the form `if(x,a,b)`, the expression will return a specified value for 'a' if the cell value it encounters in map 'x' is not zero, and a different value, specified at 'b,' if the cell value is zero. The form `if(x,a,b,c)` takes this one step further and lets you specify three different values for conditions where the cell value in 'x' is, respectively, greater than zero, equal to zero, and less than zero. Remember that 'x' is always the name of an existing map layer or a valid arithmetic or logical expression involving a map layer.

Every "if" statement has an implied or expressed "then," as well as an implied "else."

Note that there are four different forms of the "if" statement; each has slightly different capabilities, hence each will produce a somewhat different kind of result.

Refer to the GRASS User's Reference Manual; or, if you are in Gmapcalc, simply type `x=if()` to get an error message accompanied by an explanation.

The two diagrams below illustrate the action of the **Gmapcalc** if statement:

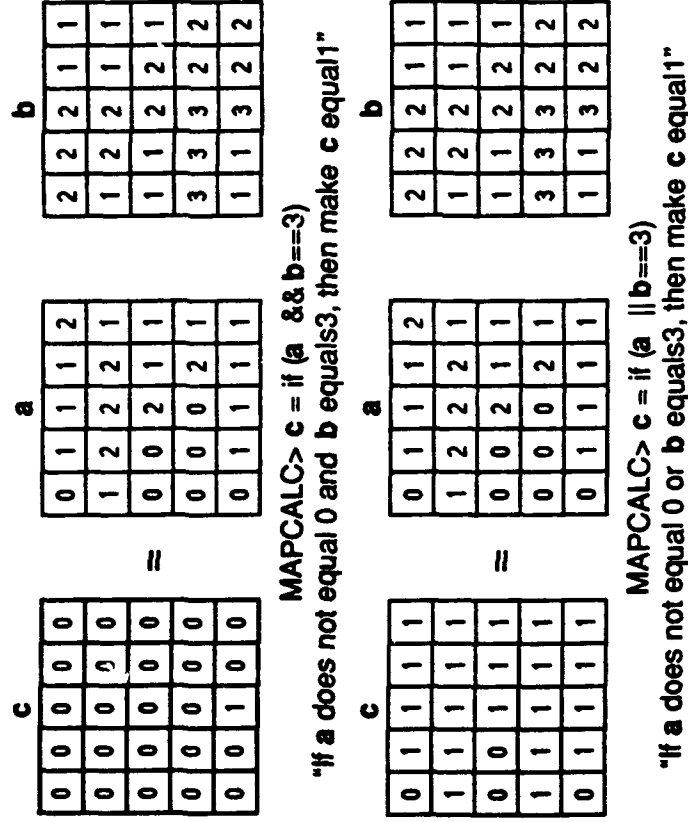


Fig. 3.3. Numerical matrices illustrating the logic and action of the **Gmapcalc** if(x) operator.

As noted previously, the **abs(x)** function converts all values of an expression to positive integers, whether they were positive or negative at the start. Similarly, the **int(x)** function will convert real (i.e., floating point, or decimal) numbers into integer values by truncating them at the decimal. If you wish to round the values returned by an equation, you simply specify **round(x)**. If you need

to convert an expression's result into floating point numbers (with decimal points), **float(x)** will do that for you.

You can also specify variables consisting of exponential functions (square, cube, sixth power, etc.) with **exp(x)**, the natural or n-base log with **log(x)** or **log(x,b)**, or the square root with **sqrt(x)**.

The **max** and **min** functions are fairly strong filters of cell values. For example, the expression:

```
MAPCALC> map1 = min ((layerA - layerB) ,(layerC - layerB))
```

will yield a map layer on which each respective cell represents the lesser value resulting from the two subtractions. These two functions would be useful in doing comparisons of change between maps of the same phenomenon in a chronological series.

Another very useful function is the "@" ('at' sign), which lets you use the actual values inside the categories of a map layer in a computation instead of the category value numbers. For example, if you specified "@soils.ph" in a **Gmapcalc** equation, it would read the actual soil pH for each category: 4.5, 5.6, 6.6, 7.4, 8.5, etc., rather than the category numbers: "@elevation.255" would do the same with the **elevation.255** map layer. Category numbers themselves are simply a convenience for ordering data and are intrinsically meaningless.

In summary, **Gmapcalc** is an extremely useful utility tool for the intermediate or experienced user, but even novice GRASS analysts will find it useful if they practice. You will find **Gmapcalc** easier to use once you begin to think within its logical and syntactical framework.

Pmap

This is the command-line version of **paint**. Although more versatile, it is also more complicated to use. In **paint**, you have no choices but default settings for such things as vector line style, UTM grid color, UTM grid number color and spacing, and other graphic elements. **Pmap** is a nearly complete cartographic toolkit that allows you to set styles and parameters for every part of your graphic output. The balance of this chapter will deal with the many options provided by this powerful tool. This discussion is only a supplement to the **Pmap** documentation in the *GRASS User's Reference Manual*; so, you might find it helpful to have a copy handy as you read through this.

Pmap allows you to enter variables and their parameters from the keyboard or from a UNIX file. You can also send the output to either a graphics monitor or to the color printer. As you familiarize yourself with **Pmap**'s commands and their products, you will probably find the preview-mode output useful. Eventually, however, you will be able to visualize what the output should look like and want to skip the preview step because you must reenter all the commands each time you make a change in the map or when you want to print it.

Once you become comfortable with the commands and syntax you will discover that it is best to create a UNIX file that you can use as standard input. A UNIX file will allow you to change commands and variables quickly and provide you with a permanent, and easily edited, record of what went into the construction of your map. It greatly simplifies debugging the **Pmap** command sequence, and making changes to earlier runs. A UNIX file is also desirable because it gives you opportunities to correct typing errors. As you develop standard setups that you use again and again, you can place those particular variable sets in separate UNIX files. You may set up many files defining **Pmap** variables which can then be called in any combination from within **Pmap**. The *GRASS User's Reference Manual* provides excellent documentation for the format of a UNIX file.

*Vector line style, vector line highlighting, outlining of cell map categories, replacing category colors with patterns, and more, are all under your control with **Pmap**. The following sections will explore the options. Start thinking of **Pmap** as a selection of cartographer's tools. To make the map you want, all you have to do is employ the right tool in the right order.*

Before running Pmap you will have to decide whether the output is to be sent to the printer for hard copy, or to the graphics monitor for preview. Once into the program, there is no indication of the painter selected at the moment. Failure to select the desired output device can cost time and consume paper and ink. The command for selecting the output device for Pmap is:

Pselect <device>
(eg.: the command **line Pselect preview** will select the graphics terminal as the output device for **Pmap**).

A sample Pmap session:

Pmap commands are entered at two levels: operations and operation-modifiers. Commands requiring more than one parameter setting use the operation-modifiers to deal with the extra variables for that command. Your GRASS User's Reference Manual provides a complete listing of operations and modifiers for each command, and the appropriate syntax. The following session schedule lists operations on numbered lines and modifiers on indented lettered lines. Note that all operation modifier sequences are required to terminate with an **end** command.

1. Select a **scale** (default is one panel).
2. Select a map to be printed.
3. If you want to paint cell map, continue with operation no. 5.
4. If you want to paint a **vector** map, go to operation no. 10.
5. Decide if you want categories to be **outlined** (default is no outline).
 - a. Select the **outline color**.
 - b. **end** outline selection.
6. Set category colors (**setcolor**) if not same as assigned color table.
7. Define pattern (**defpat**) to be used in place of the color for any or all categories.
8. Set the defined pattern (**setpat**) for the desired category.
9. Decide if a **UTM grid** is needed.
 - a. Select **grid** spacing in meters.
 - b. Select the number of lines to be numbered (if you want numbers), and select the color of those numbers.
 - c. Select **color** of the UTM lines.
 - d. **end** grid selection
10. Select **vector** file(s) to be printed(if any).
 - a. Select vector line **style**.
 - b. Select **color(s)** of the vector line
 - c. determine **width** of the vector line.

- d. Select highlight color (**hcolor**).
- e. Select highlight width (**hwidth**).
- f. Decide if you want to invoke the current **mask** and select it.
- g. **end** vector selection.
- 11. Decide if you want a color table below the output map.
- 12. Enter any additional lines to be printed on the output map, the UTM coordinates of the starting and ending points of the lines.
- 13. Indicate any additional text to be placed on the map, and its style, size, location, and color.
- 14. Indicate any labels to be placed on the map.
(You could, at this point, include **sites**, **window**, **comments**, **points**, etc.)
- 15. **end** Pmap entry.

The Pmap Operations Commands:

cell: The **cell** command is used to print a cell file (map layer). Only one map layer at a time can be printed in **Pmap**, so if you want to print two map maps at once, you must first combine them using some other GRASS function. There are no sub-commands for **cell**.

sites: This command is used to print site files on the output map. You should be aware of the modifiers **color** (for the color of the icon to represent the site on the output) and **icon** (for the type of symbol to be used at the site's location). There are no predefined icons for use in **Pmap** so you must define them first by running the program **icons** or within **paint**.

vector: This command allows you to print vector files, which involves several operation-modifiers. The **color** modifier allows you to define various parts of the vector line with a variety of colors. You can set line width (in pixels) with the **width** modifier. A width of 2 produces good results; narrower lines become dashed around tight corners, and wider lines can obliterate data, of-

ten seeming as one line where two or more lines come close to each other. The highlight color (**hcolor**) modifier provides a linear background for vector lines. Highlighting in white works well to screen background data that show through between dashes, or where a vector runs along a boundary between two categories. You use the modifier **hwidth** to set the width of the highlight line. It may be wider or narrower than the vector line it backs up, depending on the effect desired. A width equal to the vector is effective in providing a more well-defined dashed line where it crosses complex backgrounds.

The **style** command allows you to define the type of line (dotted, dashed, solid, etc.) that represents any particular vector file. You establish a style by using a series of numbers to represent individual line segments. For instance, a series of zeros and ones like 001111 will produce a line with 2 blank pixels followed by four pixels of some specified color (1). The series 0011 will produce a dotted line. The **masked(y/n)** command allows for the vector file to be either masked or not. If masked, vectors will not print in the area where the mask is operative.

labels: To put labels on the map you must first produce a labels file by running **paint**. To use this file in **Pmap**, type in **labels** followed by the file name after the > prompt.

window: This command allows you to specify a previously established window file. This window file can be produced using the **window**, **d.window**, or **Gwindow** programs.

grid: This command allows you to overlay a grid on an output map (the grid units are specified in the same units as the data base). When specifying the color of the grid lines with the **color** sub-command, you should consider the color of the map layer; for example, if the cell map is predominantly green you would not want to use green grid lines. White works well for most maps, and gray works well for subtle lines. The default color is black.

outline: This command allows you to place an outline of a specified color around each category on the cell map. It is especially helpful on maps with six to twenty categories, or on those on which the categories are defined by patterns rather than colors.

colortable: When this option is used a color table will be printed at the bottom of the map as with **paint**.

comments: If you have information you wish to print below the color table, this option allows you to enter comments as you run **Pmap**. You can also use previously prepared text files.

read: This command allows you to read a previously created UNIX file and then use it in **Pmap**. This is especially helpful when the same sites or vector files are used on many different maps.

scale: Unless otherwise specified, the default scale used by **Pmap** is one panel. Different scales may be specified in the command string, just as in **paint** (1:n, n panels, n inches, or n inches per mile).

setcolor: This command allows you to use a color other than one that is in the assigned color table without the need to run some other routine, such as **d.colors**. It is particularly useful when replacing a color with a pattern, or when highlighting a specific category. By using **setcolor** <0-n> <color>, where n is the highest category value, and color is the desired replacement, all category colors will be set to the color specified. You can also use this method to assign colors to categories according to the printer's categories by using the command string **setcolor** <n> <color table number>. Again, writing a UNIX file containing the **setcolor** assignments is the best way to proceed if there are more than a very few categories.

defpat: This routine is used to create patterns to define specified categories. You can create a pattern as described in the manual, or use any of the 252

*You can also make an outline of any cell map category with the **Gpoly** command.*

*As **Pmap** executes, each operation is printed on the terminal screen (i.e. "Reading vector _ in PERMANENT"). **verbose** allows you to suppress this 'chatter'. The same could be accomplished by running the program in the background with the **&** command.*

predefined patterns in GRASS. When you run **defpat**, predefined patterns are automatically loaded. To define your own pattern, just follow the instructions in the manual. Remember, however, that each character will occupy one pixel on your map image. But because the screen characters are taller than they are wide, your pattern will appear to be stretched on the vertical axis. It takes a while to get use to the disparity between the representation on the monitor and the actual output. Also remember that since each character represents only one pixel, the pattern will be much smaller than it appears to be on the monochrome terminal screen.

setpat: This command allows you to overlay a predefined, or user-defined pattern on a map category. The pattern is defined with **defpat**, and when assigned to a category in **setpat**, will write over the top of the color that is pre-designated for that category. If you do not want the category color that GRASS **support** has assigned, you must be set the color to white prior to running **Pmap**, or with the **setcolor** command after entering **Pmap**. Furthermore, to set the patterns to the predefined ones, each can be assigned with the command **line setpat <cat #> <pattern name>** where "pattern name" is a number between 1 and 252 with a # sign before it; for example, to assign pattern #1 to category #1 the command string would be: **setpat 1 #1**. You can also use the command **"setpat all default"** to set a random predefined pattern to all categories a command string. Because the predefined patterns tend to be rather coarse, this approach sometimes gives startling results.

The commands **text**, **line**, **point**, and **end** are well explained in the GRASS User's Manual.

Pmap's great virtue is that, like so many excellent microcomputer graphics programs, it allows you to customize graphic output to whatever extent you wish. Its great drawback is that it cannot produce WYSIWYG (What-You-See-Is-What-You-Get) graphics. However by using the preview mode and putting your command list into a shell script file, you can fine tune the graphic output

of your analyses to an extent not possible with earlier versions of GRASS, and probably not possible with many other geographic information systems.

Although this concludes our formal discussion of multilayer tools here, there are many other GRASS tools with which you need to become familiar. By the time you have worked your way through the problems in this manual you should be comfortable enough with GRASS to explore its power on your own.

Chapter Four:

PROBLEM SITUATIONS II: MULTILAYER APPLICATIONS

The following problem situations draw heavily on the use of the GRASS multilayer tools that we have just discussed, and introduce a few others. We also point out alternative ways to analyze problems. This section places a heavy emphasis on use of the GRASS to *predict* locations of phenomena that meet selected criteria rather than simply showing you where they are *known* to exist.

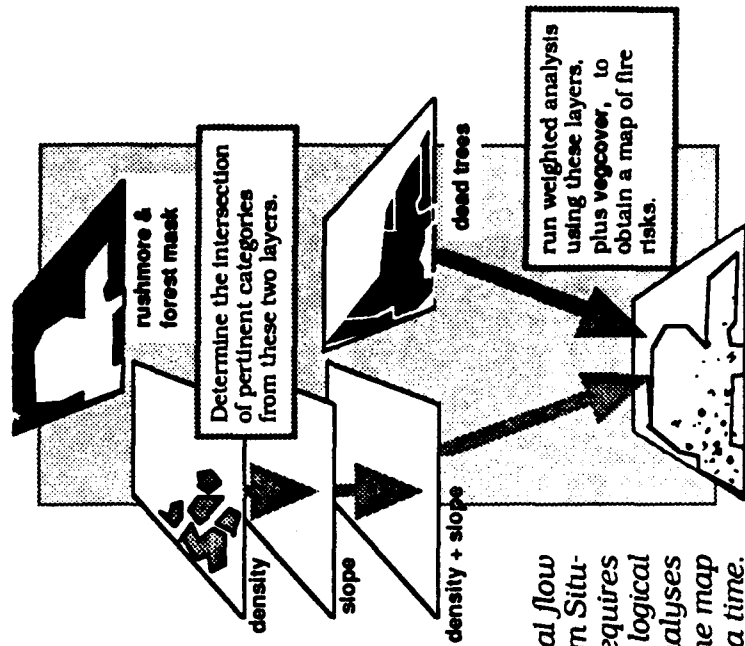


Fig. 4.1. Conceptual flow diagram for Problem Situation No. 6. It requires that you perform logical and arithmetic analyses with more than one map layer at a time.

Situation No. 6: Predicting Forest Fire Potential

Camp Rushmore shares an extensive boundary with the Black Hills National Forest. The Forest Supervisor, Charlie Waldsterben, is concerned that a wild fire starting on either agency's lands could spread to the other's. He has submitted a request to the camp commandant for an assessment of the fire potential of the forest on Camp Rushmore. The commandant has turned to you to predict the wildfire potential of all forested areas on the camp. Once identified, these areas will be field checked by Forest Service and Camp personnel.

The Forest Service has suggested that 1) dead trees, 2) high crown density, and 3) steep slopes coupled with high density forest all imply high fire potential.

Definition

The best way to show fire potential is to produce a map that shows high, medium, and low potential fire zones. To assist field crews, you should include the locations of roads and streams on the final map.

This situation is more complex than those you have encountered previously because it requires that you give relative values to the various categories. In addition to the criteria the Forest Service has provided, you know that deciduous forest is more resistant to fire than mixed forest, and that mixed forest is more resistant than coniferous forest. So, you are essentially working with four variables: type of forest, presence of high crown density, presence of dead wood, and presence of steep slopes in high density forest. You will need to assign relative values to each of these based upon its potential to increase fire danger. The values resulting from overlapping categories will generate a matrix of potential fire dangers, which you can categorize by absolute value.

The result ought to be a map which shows categories of high, medium, and low fire potential in forested areas.

Acquisition

You need a map that merges the Camp's boundary with that of the National Forest. Then you need map layers showing forest type, stand density, presence of Rocky Mountain Pine Beetle damage (implying dead wood) and slope in relation to forest density. The latter is an intermediate map layer that you will have to create.

Manipulation

You may want to create a **mask** that includes both Camp Rushmore and Black Hills National Forest lands. Use **combine** to create a map that shows where high forest **density** is congruent with **slope** greater than or equal to 25 degrees.

Next, **weight** the categories that might be factors in determining fire risk potential. **Reclass** the resultant map for high, medium, and low fire potential according to the number of criteria present in a given area. Either use **Gmapcalc** to differentiate areas outside the mask from the categories inside it, or use **patch** to insert your analysis for the camp into any Spearfish data base map layer.

1. Create or reset an appropriate **mask**.
2. In **combine**, intersect (and) category 7 of **slope.7** (greater than 25°) with category 4 of **density** (high forest density) and name the new map something like **slope.dens**.
3. Enter **weight** and choose all the map layers you will be using in your weighted analysis.

Or, if you want to try Gmapcalc again, the following command will do the same thing as step 2:

```
Mapcalc> slope.dens = 'if
(slope.7 ==7 && density ==4, 1)';
```

Do you see how they are the same?

4. Assign relative values to the appropriate categories of the map layers you have chosen: category 3 (coniferous forest) of **vegcover** = 3 because it is the highest risk, category 4 (deciduous forest) = 1 because it is the lowest risk, and category 5 (mixed forest) = 2. Similarly category 1 of **bugs.dist** = 1, and category 1 of **slope.dens** = 1. Remember to save your analysis before you execute it. Name the analysis **fire.danger**.
5. **Reclass fire.danger** categories 1-2 as category 1 (low fire potential), categories 3-4 as 2 (medium), and 5 as 3 (high). Name this new map **fire.potential**.

Generation

Use **Pmap** to print out a hard copy map that includes vector maps of roads and/or streams.

For your own location you might have a more sophisticated database that enables you to make more subtle distinctions. For example, the presence of high crown density might be 2.7 times as potentially dangerous as the presence of dead wood. Here, however, we have assumed that fire danger increases in linear fashion for each type of forest.

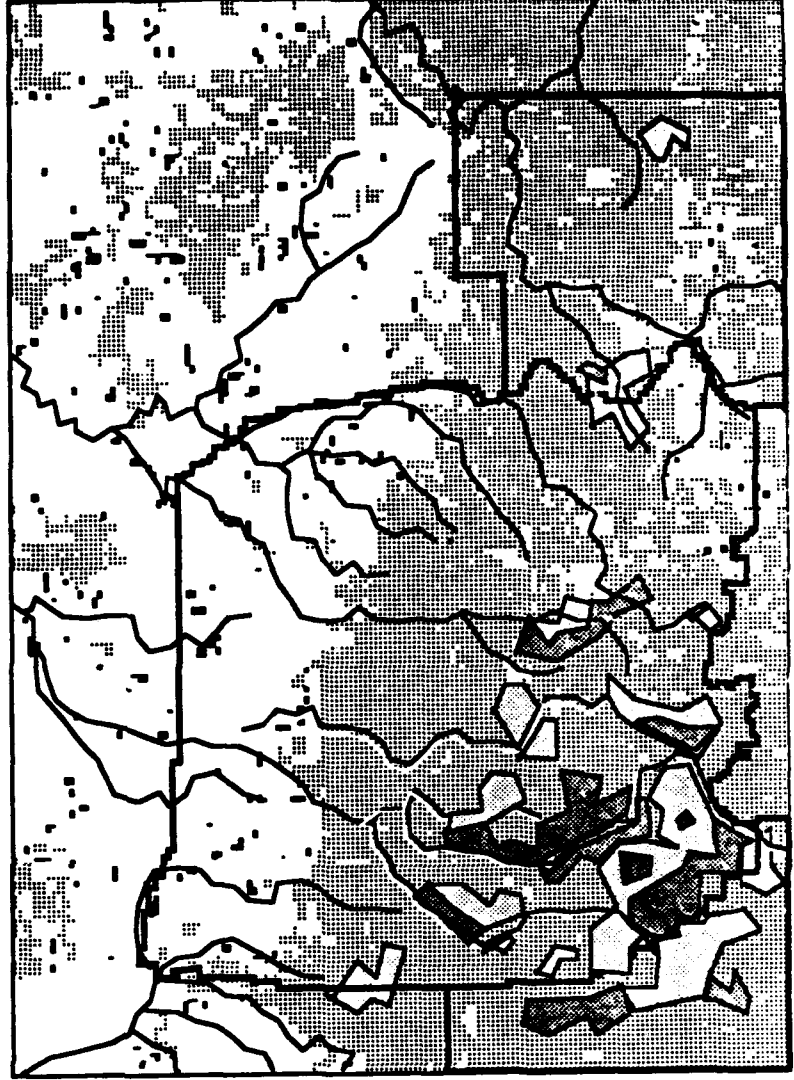


Fig. 4.2. An approximation of the fire.potentials map. The shaded polygons represent areas of high or medium potential risk. The background shading is from the woodland layer you created earlier.

Situation 7: Screening Data for Selected Characteristics

Charlie Waldsterben comes back a week or two later and says, "Look, since we're assessing fire potential, why don't we locate some potential helicopter landing sites...on both your land and ours...so we can drop off fire crews in a hurry." You agree, but secretly wish the Forest Service would buy Charlie his own GRASS workstation!

Although no strict guidelines for landing pad locations have been established, a preliminary telephone conversation with the District Office's Chief of Fire Crews (CFC) has provided you with some general USFS criteria. Landing sites should be:

1. approximately circular and at least five acres in extent,
2. within a quarter-mile of an existing forest road,
3. on relatively flat ground,
4. in low density forest,
5. on stable soil, and
6. more than 200 meters from any stream.

The CFC suggests that you try to locate a minimum of 20 sites distributed throughout the wooded areas of the camp. If you can't find 20 sites that satisfy all these conditions, he has asked that you indicate marginal sites to make up the difference. These sites may be, first, as small as 2.5 acres; second, only 100 meters from streams; or, third, as much as a half-mile from a road.

Definition

At first this would seem to be simply a question of showing sites that satisfied all six criteria for landing zones. Criterion 1, however, specifies a shape and

size for each site. While GRASS can tell you the size of an area once it has been created, it cannot easily create areas of a given size or shape that meet the other criteria. You could find areas that satisfy criteria 2 through 6 and then manually locate landing sites by shape and size within these areas. These areas could then be given separate identities with **clump** and incorporated as a map layer in the GRASS data base.

On the other hand, you know from your experience with military helicopter landing zone preparation that the Forest Service specs are too restrictive. What is really important is getting adequate fire protection coverage, so you could simply isolate the areas of major concern and distribute landing sites uniformly around it. This gives you two different strategies for dealing with the problem and a chance to see which might work best.

Acquisition

To get started, you will need the map layers named **streams**, **slope**, **density**, and **soils.texture**. You will have to create intermediate zone maps of **roads** and **streams** using **distance**. You may wish to **reclass soils.texture** to exclude undesirable soil types, or you can simply select the appropriate soil types in **combine** by using the group function.

Manipulation

You may want to use a **mask** of Camp Rushmore and National Forest lands, or it might be sufficient to simply superimpose the outlines of the Camp and the National Forest on your final map. You will also need to create

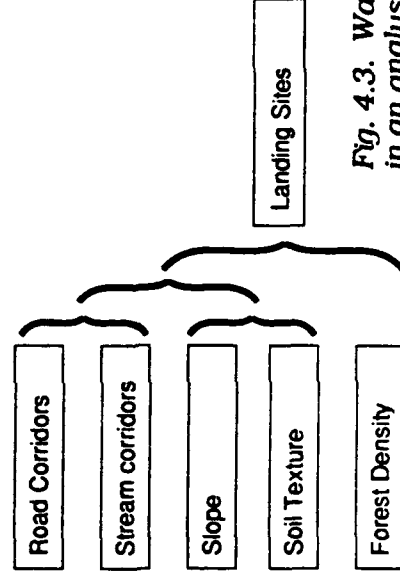


Fig. 4.3. Ways of pairing map layers in an analysis using **combine**.

Your problem here is to extract pertinent data categories from several map layers to generate the map of landing sites, as in the diagram at left.

*While **combine** allows you to work with more than two maps at once, it is less confusing to work with them in pairs at first.*

combine, more than the other multilayer tools, requires that you learn the syntax of its command statements. One thing you will have to do is to tell it specifically which categories (groups) you want to include in your analysis.

For example, you will have to know which soil categories comprise 'stable soil.'

Appendix I lists data base categories.

You will not need to reclass slope or density as intermediate maps because combine allows you to choose the categories that you will combine with other map layers. Remember, too, that any Boolean analysis in combine results in a binary map layer.

intermediate maps of streams and roads using **distance**. Eliminate the sandiest soils by using **reclass** or **combine** on **soils.texture** and intersect the new map with **slope.7** to create an intermediate layer of gentler slopes and more erosion resistant soils. And, finally, intersect the intermediate streams/roads map with the **soils/slope** map to create a third intermediate. Finally, you can intersect this with the pertinent categories of **density**, which should result in a map on which you can locate possible landing sites.

If the indicated potential areas do not allow you to distribute 20 landing sites uniformly throughout the forested area, you will want to try to locate alternative sites by applying less stringent criteria. If this does not provide sufficient distribution, use the alternate approach with **random** and **clump**.

1. Set a **mask** (optional).
2. Use **distance** on **streams** and **roads** to create maps showing a 200 meter zone along streams and a 400 meter zone along roads. Call these **strms.zone** and **rds.zone**.
3. In **combine**, intersect (and) **strms.zone** and **rds.zone**; name the new map **strms.rds**.
4. Still within **combine**, intersect non-sandy categories from **soils.texture** and the more gently sloping categories from **slope**; name this new binary map **soil.slope**.
5. Continuing in **combine**, intersect category 1 of **strms.rds** and category 1 of **soil.slope**. Give this new map the name **strm_rd.soil_slope**.
6. **Combine** category 1 of **strm_rd.soil_slope** and category 2 of **density**. Name this new map **landing.sites**.

If you followed these steps correctly, then **landing.sites** will show that there are no possible helicopter landing sites. Obviously the criteria are too strict. It is time to redefine and reevaluate the problem. Go back and try the analysis

with different criteria and see what you can come up with. For example, soil type may not matter, or perhaps some stumps can be removed, which means that the forest density can be greater.

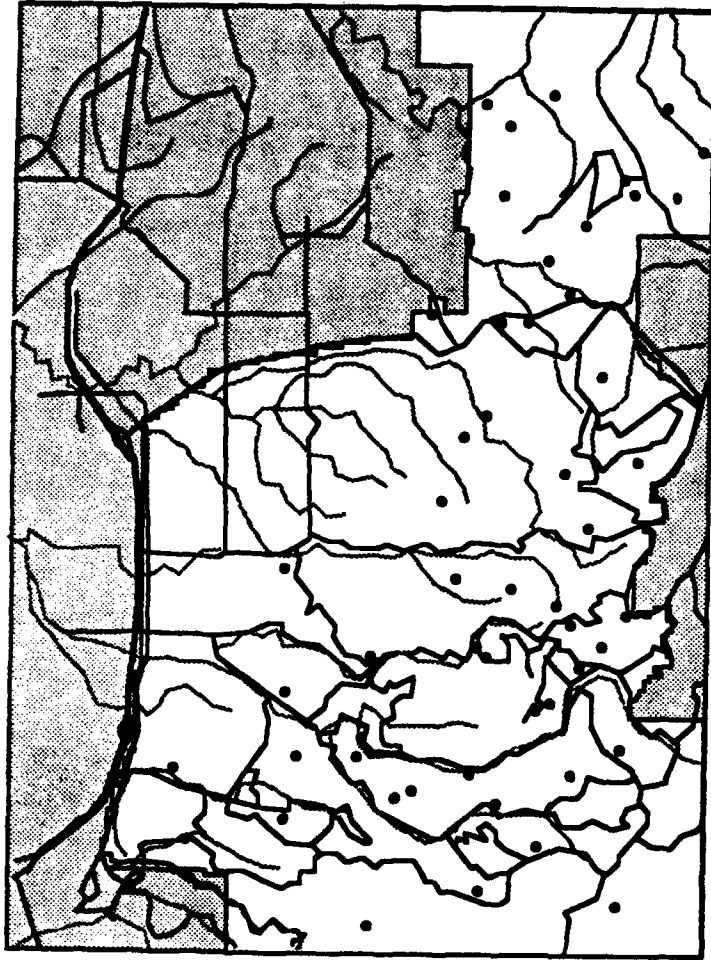
An alternative method of analysis might be to:

1. Set a **mask** that excludes everything except Camp Rushmore and National Forest lands.
2. Create and save the road and stream corridor maps using **distance**, just as in the previous solution.
3. Using the map layer called **woodland** (from Situation No. 3), run the random point generator, **random**. Have it select, say, 50 points within the mask. All of these points will have a cell value of 1 and fall within the forested area. You will be asked to give a name to the map of random points.
4. Next, run **clump** on the 50 points. This will assign each point (cell) to a separate category, giving you up to fifty categories.
5. Now, run **Dwhat**, to search your random point map layer, the two corridor maps, **slope.7**, **soils.texture**, and **density**. Place the cursor on each of your fifty random points in turn and check the characteristics of the site. You may want to modify your mask at this point to eliminate points that fall within road and stream corridors.
6. At this point you must decide which of the sites are the best potential landing sites by comparing the information provided by **Dwhat**. Keep track of the twenty or so best sites and then use **reclass** on the **clumped** map layer to eliminate the others.

There is another way to attack this problem..

*Since your points have been chosen at random, some may be adjacent at top, bottom, or sides - **clump** will assign such groups as these to single categories.*

*Fig. 4.4. Fifty randomly selected sites (cells) for helicopter landing pads located within the combined boundaries of Camp Rushmore and the Black Hills National Forest. Roads and streams are shown for orientation purposes. The 50 sites could be isolated into individual categories using **clump** or **Gclump** and then tested for suitability using **Dwhat**.*



Generation

You now need to generate a map that shows the twenty best landing sites. You have several options. First, you can simply print the map that resulted from your analysis, with roads, streams, etc. added for reference. Second, you can create a **sites** list of the locations and use that to make a map with the landing sites depicted as vector symbols. Third, you can make a composite using other GRASS tools and techniques. We will let you turn your own creativity loose on this one. As always, consult the *GRASS User's Reference Manual* for inspiration and guidance.

Situation No. 8: Mapping Potential Occurrence of an Endangered Species

You are the Environmental Manager for Camp Rushmore. This morning, your boss tells you that the base commander has learned from a golfing partner—a local lawyer who is also a member of the Spearfish Native Plant Society—that a member of that organization has found a patch of the rare Rosy Wolf-Violet, *Violobos rosaceus*, very near the camp boundary. He hands you a sketch map showing the location (see below) and says that it would be an awfully good idea for you to tell the trainers whether there are any Wolf-Violets growing on the post, because in two weeks trainers have a major armored infantry exercise planned. If an armored personnel carrier runs over any Wolf-violets, there will be trouble.

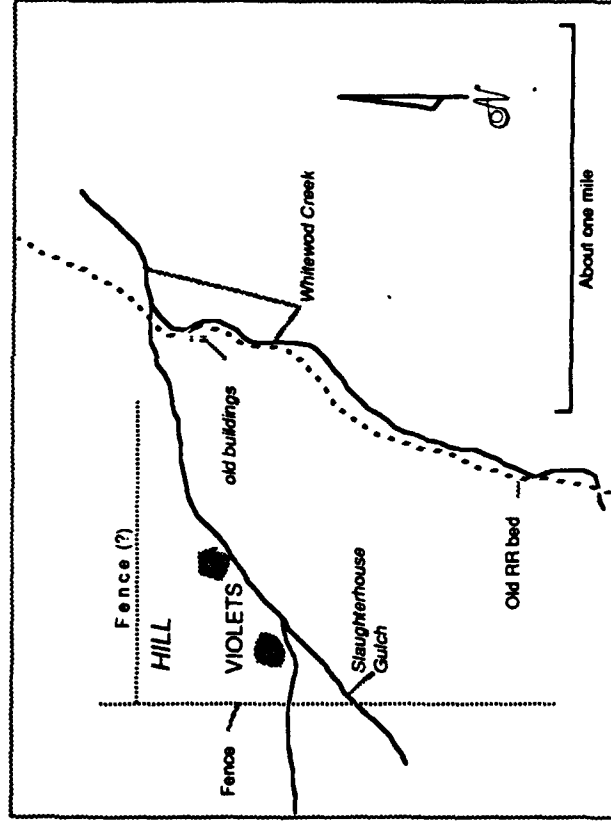


Fig. 4.5. Sketch map of the Slaughterhouse Gulch Wolf-violet locality provided by the Camp Commander's golfing partner.

Next, you need to try to deduce some of *Violobos*' habitat requirements. The tool to use is **Dwhat**. But before using it you must decide which map layers in the database are worth querying. You must also decide how much faith to place in any single query. Should you take just a single reading at each of the two locations, or should you take more, in the immediate vicinity, to try to determine the probable *average* conditions under which they grow? This type of question really tests your faith in the accuracy of your data base.

Once you know what characteristics you're looking for, the manipulation of data is a fairly straightforward analysis in **combine** or **weight**, or a combination of the two. Your tool of choice is the one that will filter out the extraneous data and leave you with either a single category representing the conjunction of necessary habitat conditions, or up to three categories indicating the relative probability of finding violets.

1. Make a map of known locations using **sites** or the on-screen digitizer in **display**. Call the new map **violets**.
2. Use **Dwhat** to find the categories on your selected map layers that fall in and around the known locations. These categories describe the kinds of areas you are seeking in the remainder of your analysis.

Generation:

The result of your efforts should be a map that shows all of the potential growth sites for *Violobos rosaceus*. These sites would then have to be surveyed on foot, by a competent botanist, to determine if there are really violets there. It is important that you include enough information on your map for the survey team to find the sites you have identified.

Suggestion: Turn each of the violet-sightings locations into a 9- or 25-pixel square and determine the average conditions within each square for each of the data layers you query. The rationale for this is that you don't want to be too exclusive in defining potential locations. Under the circumstances, it's better to find too much potential area rather than too little, right?

What information do you have in the database that will provide you with all the things you need to know?

Situation No. 9: Mapping Potential Occurrence of Archaeological Sites

The camp Commander, Col. Jones, while on a recent hunting trip with some friends, was introduced to Congressman Ole Erickson, long-time resident and enthusiastic amateur archaeologist. Erickson mentioned that he was very interested in Paleolndian klll sites and thought that Camp Rushmore might contain quite a few of them. He offered to assist camp personnel in locating any sites, reminding the Colonel that the National Historic Preservation Act of 1966 requires this sort of survey.

The Colonel has agreed to a survey, and Erickson has provided a map of eight sites that he has found in the past few years. All but one are outside the

camp. The Congressman's time in his district is necessarily limited. Col. Jones' concern is how to most efficiently undertake a systematic search for all potential Paleoindian sites on the installation. So it is up to you to try to create a logical plan of attack for finding sites.

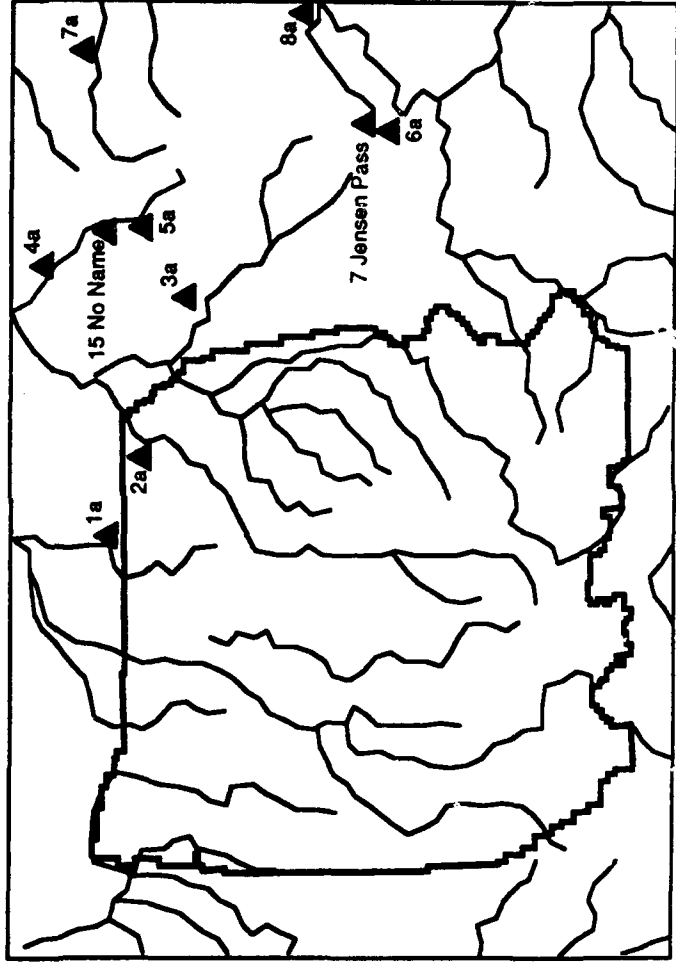


Fig. 4.6. *Approximate locations of all the Paleo-Indian sites known in the Spearfish area. To avoid confusion with sites already recorded in the data base, all sites located by Congressman Erickson are designated with an **a**.*

Definition

Your initial problem is deducing what criteria these early hunters used to decide where to locate their sites. Keep in mind that factors that operated in the past may or may not even exist today. Also, these are kill sites, not habitation sites, so their location would be determined by the increased probability of immobilizing and killing large game. Kill sites are found mainly on the paths of ancient bison migration routes. The ancient Indians would try to ambush a herd in narrow ravines or in marshy areas, or they would try to drive the animals off cliffs to disable them and provide a better chance for a successful hunt. Such sites commonly contain one or more of the following: various sharp-edged flakes and scrapers of flint-like (cryptocrystalline) material, Angostura spear points, carbon from cooking fire hearths, and faunal remains (bones).

Because past conditions no longer exist and you don't have a map of ancient bison migration routes, one way of obtaining the information needed is to try to find conditions of terrain, vegetation, soils, etc. that are analogous to those that exist in known sites. You must now consider the relative importance of environmental factors, asking such questions as: How important was proximity to water? Did either Paleoindians or the game favor certain vegetation or elevational zones? Since you don't know precisely how conditions have changed in the intervening millennia, you will have to rely upon simple statistical approximations of past conditions.

Acquisition

The first thing you need is the map that Rep. Erickson has provided to make a list of existing sites. Next, you need to assess the contents of your data base to select the map layers that are most likely to tell you something useful about potential kill site locations. For example, you may find that most of the sites fall in a fairly narrow range of elevation, or are associated with particular landforms. Much of this assessment ought to be done by scrutinizing the top-

68 The GRASS Problem-Solving Manual

The sites program, described here, is an extremely useful tool for analyzing any kind of point data. It functions rather like a relational database, in that you can attach attributes to point identification numbers and geographic locations, plot them on a map, and run statistical measurements on them.

ographic quadrangle maps on which you have plotted site locations. You can then use GRASS tools to confirm or negate your deductions.

Manipulation

A good place to begin your search is by making statistical correlations between relevant categories on data base map layers and conditions surrounding already discovered sites. You can do this in GRASS with the tool named **sites**, which allows you to match site locations with environmental data from map layers. It can generate spatial analysis reports or export data to the **g** statistical package. In general, **sites** provides a means to manipulate site tables, containing site identification numbers, UTM eastings and northings, and additional attributes. All information in the list must have the same format. For a more complete description of **sites** consult the GRASS User's Reference Manual.

SITE NAME	UTM EASTING	UTM NORTHING
1a	508346	4525584
2a	509752	4521931
3a	503165	4521261
4a	503167	4521999
5a	507025	4525345
6a	508346	4521236
7a	507889	4521423
8a	508346	4521561

Site information from any source must be entered into a site information table. You already have a listing of twenty-five known archaeological sites in the Spearfish area in your database. Two of these are Paleoindian sites. The Congressman has been kind enough to supply a map of the eight additional sites he has located. Someone else has worked out the UTM coordinates for you. Data for the site information table are given at the left.

Chi-squared analyses specifically do not tell you if the sets of phenomena are associated, or linked in some sort of cause-effect relationship.

Within **sites**, you need to add the new sites to the list and then create a new list that contains only Paleoindian sites. You can then run site occurrence reports to find which categories from various map layers might have some statistical relationship. The statistical measure that **sites** uses for this is Chi-squared (χ^2). This calculation is used in situations where it is necessary to

It might be useful to obtain a book on basic statistics for reference.

test the likelihood that frequencies of occurrence in one set of phenomena might be influenced by frequencies of occurrence of some other phenomena. It provides a measure of the relative dependence or independence between the actual occurrence and an assumed occurrence based on the distribution of frequencies for some other factor (such as soil or vegetation type) and suggests the probability that the observed distribution is not random. Thus, the more that observed distributions approximate those based on pure chance, the lower the probability that it was caused by some determinant factor, and the smaller the value of X^2 . Conversely, the greater the departure of the observed distribution from what would be expected on the basis of chance, the higher is the probability that it is associated with some suspected other factor.

The probability is directly affected by the *degrees of freedom* (df) allowed by the sample universe. Degree of freedom is a measure of how reliable the X^2 value is. It is based, in large part, on the number of categories or individuals in your sample. In general, the more categories, the greater the degrees of freedom, and the more reliable the value as a measure of statistical significance. To find actual probability, look up the value that resulted from your X^2 computation in a table of X^2 values (these can be found in most books of statistical tables). Find the value in the table that is closest to your X^2 value in the row that represents the degrees of freedom provided by the computation. At the top of that column, is the probability (P) that your observed frequencies are not due to chance; the closer to .01, the better.

Because GRASS gives you the ability to screen and compare data rapidly, you can easily run through a number of analytical permutations and develop a feel for possible relationships among the data. To screen for possible site locations, the most direct approach is to revise the site list, in sites, and prepare site occurrence reports using different map layers such as **vegcover** or **slope** to see if the known sites tend to occur in conjunction with certain categories of

Fig. 4.7. A typical Site Occurrence Report produced by sites. This one demonstrates a very small degree of relationship between site occurrences and categories in the range.soils map layer. There is a 90-95 % probability that the distribution is random.

SITE OCCURRENCE REPORT Speerfish, SD									
Location: speerfish									
Mapset: sandya									
Site List: paleosites - Potential Paleocindian sites (10 sites)									
Analysis Window:									
west: 590000.00 north: 4928000.00 east: 609000.00									
south: 4914000.00									
Layer: soils.range	Range type								
cells in analysis window:	26800								
sites in analysis window:	10								
Site Characteristics	cells cover	% cover	expected sites	actual sites	Chi squared	degrees of freedom			
(0) no data	11427			0					
(1) sandy	8	0.1	0.0	0	0.005	1			
(2) silty	8310	54.8	5.5	6	0.050	1			
(3) shallow	929	6.1	0.6	1	0.246	1			
(4) shallow, silty	443	2.9	0.3	0	0.282	1			
(5) shallow, thin upland	57	0.4	0.0	0	0.038	1			
(6) thin upland	1581	10.4	1.0	1	0.002	1			
(7) clayey	2530	16.7	1.7	1	0.267	1			
(8) shallow clay, clayey	288	1.9	0.2	1	3.458	1			
(9) shallow to gravel	427	2.8	0.3	0	0.281	1			
(10) thin claypan	68	0.4	0.0	0	0.045	1			
(11) subirrigated	7	0.0	0.0	0	0.005	1			
(12) overflow	525	3.5	0.3	0	0.346	1			
TOTALS	15173	100.0	10.0	10	5.043	11			

Fig. 4.8. Another Site Occurrence Report produced by sites. In this there is only a 10-20% chance that the association was caused by chance distribution.

SITE OCCURRENCE REPORT									
Spearfish, SD									
Location: spearfish									
Mapset: sandy's									
Site List: paleosites - Potential PaleoIndian sites (10 sites)									
Analysis Window:									
west: 590000.00 north: 4928000.00 east: 609000.00									
south: 4914000.00									
Layer: slope.r reclassified slope									
cells in analysis window: 26600									
sites in analysis window: 10									
Site Characteristics		cells cover	% cover	expected sites	actual sites	Chi squared	degrees of freedom		
(0) no data		18018			0				
(1) 0-24		6969	81.2	8.1	10	0.435	1		
(2) 25 and up		1613	18.8	1.9	0	1.880	1		
TOTALS		8582	100.0	10.0	10	2.315	1		

environmental conditions. You can also use intermediate maps like distance from streams (sirms.dlist). Map layers such as landuse are of little or no use since none of the information it contains relates to the PaleoIndian era. If you think you detect a trend, or an implied association, check your results against the X^2 table. If you see a trend that the X^2 value does not support, you can try reclassing the map layer and re-running the analysis to see if you get different results.

Once you find some map layers/categories that show promise statistically, use a multi-layer tool like **weight** or **combine** to produce the final analysis. You should be able to produce a map with areas showing significant probability for Paleoindian sites. You can then use **Gmapcalc** and/or **Gresample** to differentiate areas of low probability from the No Data areas created by any mask you have set, and to emphasize areas of higher probability. The last steps are to **reclass** the map to make it easier to read and to add reference information that will help the archaeological survey crews when they take to the field.

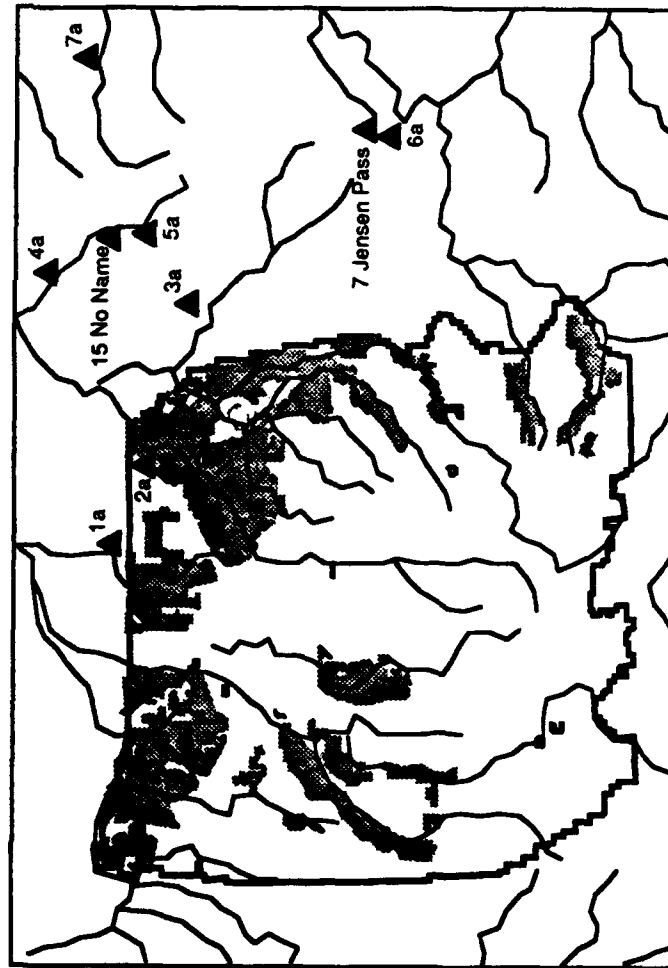
1. Run **sites**; edit the data base site list to include the eight new sites and sort the revised list to prepare a table containing only Paleoindian sites.
2. Run a site occurrence reports on the site list using various map layers including **vegcover**, **soils.br.depth**, **soils.br.depth**, **aspect**, **elevation**, and **slope** 7. Use some intermediate map layers like **strms.dist**. When **sites** asks you how many cells to include around the point locations, choose option 2.
3. **Reclass** the **aspect** map layer to E facing, NE facing, N facing, NW facing, W facing, SW facing, S facing, SE facing, and no aspect. Run a new site occurrence report on it.
4. When you have completed the previous steps, look up all the X^2 values and decide if there are any categories on any of the map layers that include more sites than would be explained by chance alone.
5. Run **weight** on **vegcover**, **slope**, **soils.texture**, **soils.br.depth**, reclassified **aspect**, and **strms.dist**. Give weights of 1 to categories 1, 2, and 6 on **vegcover**; categories 1-6 on **slope**; category 3 on **soils.texture**; categories 1 and 2 on **soils.br.depth**; categories 2, 3, and 4 on reclassified **aspect**; and category 1 on **strms.dist**. Give a weight of 2 to categories 1, 6, 7, and 8 on your reclassified **aspect** map. This results in 8 categories.
6. Add 1 to every category of the resultant map with **Gmapcalc**.

Higher weights are given to aspects having greater significance in the site occurrence frequency tables.

7. Put the **rushmore** mask over this map and run **Gresample** to reduce the total number of categories to eight.
8. Remove the mask.
9. **Reclass** the map to high, medium, low and no potential of containing Paleoindian sites. Category 1 will indicate no potential; 2 and 3, low potential; 4 and 5, medium potential; and 6, 7, and 8, high potential.
10. You may wish to revise the color table, using **support**, **d.colors**, or **display**.

Generation

1. Use **Pmap** to design and print the final map (which will display more categories than the one below).



Pmap will allow you to add or create labels to your output map. As noted in Chapter 3, it is a good idea to build a command file in vi (or some other text editor) and use that to create your final report map.

Fig. 4.9. Areas having a high probability of containing Paleoindian kill sites, based on weighted analysis. This simplification shows only areas of high potential. Your map will show all four levels.

Technical Note on Production.

Text and page layout for this manual was prepared on an Apple Macintosh® using

ReadySetGo 4.5a® software.

Body text and titles were set in the Bookman family of fonts. Supplemental text was set in Helvetica, and marginalia in

Zapf Chancery.

Illustrative graphics were prepared in SuperPaint 2.0® and MacDraw II®.

Final production was done on an Apple LaserWriter Plus®.

Page design and illustrations are the work of the author.

APPENDICES

CONTENTS

- One** Spearfish, South Dakota, Permanent Map Layers
(A Data Base Category List).
- Two** Short Descriptions of Archaeological Sites in the
Spearfish, South Dakota, Area.
- Three** Keystroke Guide To Procedures, Problems 1
through 6.

Appendix One

Spearfish, South Dakota: Permanent Map Layers (Cell Files Only)

Topographic Data Files

aspect

0	No Data	13	West facing
1	East facing	14	15° South of West
2	15° North of East	15	30° South of West
3	30° North of East	16	Southwest facing
4	Northeast facing	17	30° West of South
5	30° East of North	18	15° West of South
6	15° East of North	19	South facing
7	North facing	20	15° East of South
8	15° West of North	21	30° East of South
9	30° West of North	22	Southeast facing
10	Northwest facing	23	30° South of East
11	30° North of West	24	15° South of East
12	15° North of West	25	No Aspect

elevation

[Raw elevation data in 1 meter increments with category values corresponding to actual elevation]/ 1840 categories

elevation.255

[elevation reduced to 256 categories]

0	No Data
1	1066 through 1068 meters, then in 3 meter increments to . . .
255	1827 through 1828 meters.

slope

0	No Data	4	7-10 degrees
1	0-2 degrees	5	10-15 degrees
2	2-5 degree	6	15-25 degrees
3	5-7degrees	7	25 degrees and up

bugsites

[Rocky Mountain Mountain Pine Beetle damage]*

- 0 No Data
- 1 No MPB damage (Largely confined to Ponderosa Pine)
- 2 Area where MPB damage has occurred
- * Sites were identified from a September 1976 high-altitude aerial photograph.

density

[Timber Density]*

- 0 No Data
- 1 Non-forest (actually non-coniferous forest)
- 2 Low density
- 3 Medium density
- 4 High density
- * Produced from September 1979 LANDSAT data. Classes represent relative crown closure for coniferous forest land.

fields

[Cropland parcels as identified on Soil Conservation Service rolls]*

- 0 No Data
- 1-62 Fields, identified by owner and owner's parcel number
- 63 Black hills National Forest
- * Parcels belong to 16 different owners.

geology

[Surface Geology]

- 0 No Data
- 1 Metamorphic
- 2 Transition
- 3 Igneous
- 4 Sandstone
- 5 Limestone
- 6 Shale
- 7 Sandy Shale
- 8 Clay
- 9 Clay-sand
- 10 Sand

landuse

[Undifferentiated vegetation]

- 0 No Data (Undifferentiated vegetation)
- 1 Residential
- 2 Commercial
- 3 Industrial
- 4 Other urban
- 5 Reservoirs
- 6 Bare exposed rock
- 7 Quarries, mines, gravel pits
- 8 Transportation and utilities

A.4 The GRASS Problem-Solving Manual

mss.image

[Enhanced LANDSAT image prepared with GRASS imagery]

- 0 No Data
- 1-215 Categories proportional to reflectance values of data

owner

[Land Ownership]

- 0 Background;
- 1 Private ownership
- 2 National Forest, USFS, Black Hills National Forest

quads

- 0 No Data
- 1 Spearfish
- 2 Deadwood North

railroads

- 0 No Data
- 1 Railroad

roads

- 0 Background
 - 1 Primary route, undivided
 - 2 Road or street, class 3
 - 3 Road or street, class 4
 - 4 Trail, class 4, non-4 wheel drive vehicle
 - 5 Cloverleaf or interchange
- Area with no roads
Asphalt- and concrete surfaced.
Ditto
Regularly maintained, all-season gravel.
Irregularly maintained, seasonal road; untreated soil surface.

restrict.areas

[Areas closed to normal access]

- 0 No Data
- 1 Off Limits (golf course)
- 2 Off Limits (campground)
- 3 Artillery Impact Area
- 4 Restricted Area

soils*Soil Series Data*

Beginning at left are the data categories for the map layer entitled **soils**. Other soil characteristic map layers included in the data base are: **soils.br.depth**, **soils.ph**, **soils.range**, **soils**, **Tfactor**, and **soils.texture**. These are grouped on the following pages.

Cal. No.	CLASS NAME	Slope Range	Site Indx	Dwellings Without Basements	Dwellings With Basements	Septic Tank Absorption Fields
1	Alice fine sandy loam	0-6		Slight	Slight	Slight
2	Boneck silt loam	2-6		Moderate	Moderate	Moderate
3	Boneck silt loam	6-9		Moderate	Moderate	Moderate
4	Butche stoney loam	6-9		Severe	Severe	Severe
5	Butche-rock outcrop	25-50		Severe	Severe	Severe
6	Butche-Satanta loams	6-25		Moderate	Moderate	Moderate
7	Canyon-Bridget complex	6-25		Moderate	Moderate	Moderate
8	Canyon-Bridget complex	9-50	65	Severe	Severe	Severe
9	Citadel Association, hilly			Severe	Severe	Severe
10	Mine Dumps					
11	Enning-Minnequa silty clay loam	6-25		Moderate	Moderate	Moderate
12	Glenberg Variant fine sandy loam		60	Severe	Severe	Severe
13	Grizzly-Virkula association			Severe	Severe	Severe
14	Gummit-rock outcrop	3-20		Severe	Severe	Severe
15	Gummit-rock outcrop	15-50		Severe	Severe	Severe
16	Gypnevee-Rekop loams	6-25		Moderate	Moderate	Moderate
17	Higgins silt loam			Severe	Severe	Severe
18	Hsega-rock outcrop		60	Severe	Severe	Severe
19	Hisle silt loam	0-3		Severe	Severe	Severe
20	Kyle clay	2-6		Severe	Severe	Severe
21	Lakoa silt loam	25-50	60	Severe	Severe	Severe
22	Maitland loam	2-9	65	Severe	Severe	Severe
23	Maitland loam	9-50	65	Moderate	Moderate	Moderate
24	Midway-Razor silty clay loam	6-25		Severe	Severe	Severe
25	Nevee silt loam	2-6		Severe	Severe	Severe
26	Nevee silt loam	6-9		Moderate	Moderate	Moderate
27	Nevee-Spearfish-rock outcrop	9-40		Moderate	Moderate	Moderate
28	Nihill gravelly loam	6-25		Moderate	Moderate	Moderate
29	Nunn clay loam	0-2		Severe	Severe	Severe
30	Nunn clay loam	2-6		Severe	Severe	Severe
31	Nunn clay loam	6-9		Severe	Severe	Severe
32	Paunsagunt-rock outcrop	6-50	45	Severe	Severe	Severe
33	Pierre clay	2-6		Severe	Severe	Severe
34	Pierre clay	6-25		Severe	Severe	Severe
35	Quarry pits					
36	Rekop-Gypnevee-rock outcrop	15-50		Moderate	Moderate	Moderate
37	Rock outcrop-Pactola association		60	Severe	Severe	Severe
38	Rock outcrop-Vanocker association		60	Severe	Severe	Severe
39	Satanta loam	0-2		Severe	Severe	Severe
40	Satanta loam	2-6		Moderate	Moderate	Slight

A.6 The GRASS Problem-Solving Manual

soils (continued)

Cal. No.	CLASS NAME	Slope Range	Site Indx	Dwellings Without Basements	Dwellings With Basements	Septic Tank Absorption Fields
41	Savo silt loam	0-2		Severe	Severe	Severe
42	Savo silt loam	2-6		Severe	Severe	Severe
43	Stetter variant silty clay loam			Severe	Severe	Severe
44	St. Onge loam	0-2		Severe	Severe	Severe
45	Swint silt loam			Severe	Severe	Severe
46	Tilford silt loam	0-2		Slight	Slight	Slight
47	Tilford silt loam [empty category]	2-6		Slight	Slight	Slight
48	Tilford silt loam	6-9		Slight	Slight	Slight
49	Vale silt loam	0-2		Slight	Slight	Slight
50	Vale silt loam	2-6		Slight	Slight	Slight
51	Vale silt loam	6-9		Slight	Slight	Slight
52	Vanocker-Citadel association		60	Severe	Severe	Severe
53	Weber loam	0-2		Slight	Slight	Slight
54	Winetti cobbly loam			Severe	Severe	Severe
55	Water					

Soils data from: *Soil Survey of Laurence County, South Dakota, 1979.*

NOTE: Associations or complex map units with dual or multiple ratings for Woodland Site Indices were assigned the highest specified rating. In most cases, the presence of steep slopes should result in a lower rating.

soils.br.depth

0	No Data	3	≥20 and <40 inches
1	<14 inches	4	≥40 and <60 [no data in this range]
2	≥14 and <20 inches	5	>60 inches

soils.ph

0	No Data	3	≥6.6 and <7.4
1	≥4.5 and <5.6	4	≥7.4 and <8.5
2	≥5.6 and <6.6	5	≥8.5

soils.range

0	No Data	
1	Sandy	
2	Silty	
3	Shallow	
4	Shallow, silty	
5	Shallow, thin upland	
6	Thin upland	
7	Clayey	
8	Shallow clay, clayey	
9	Shallow to gravel	
10	Thin clay pan	
11	Sub-irrigated	
12	Overflow	

soils.Tfactor /Potential Soil Loss in Tons per Acre per Year/

0	No Data	3	T of 3
1	T of 1	4	T of 4
2	T of 2	5	T of 5

soils.texture

0	No Data	9	Gravelly silt loam
1	Loam	10	Gravelly silt loam, loam
2	Stony loam	11	Cobbly loam
3	Silty loam	12	V. grav. silt loam, grav. s. loam, s. loam
4	Silt loam, loam	13	Clay
5	Fine sandy loam	14	Clay loam
6	Loam, Fine sandy loam	15	Silty clay loam
7	Loam, v. fine sandy loam	16	Silty clay loam, clay
8	Gravelly loam	17	Silty clay loam, silty clay

streams

0	No Data (Background)	Areas without streams.
1	Perennial streams	Streams with year-round flow.
2	Intermittent streams	Streams in which flow is only seasonal.
3	Aqueduct	
4	Shoreline	

strm.dist

0	Cells from which distance is calculated
1	0 to 300 meters from a stream
2	More than 300 meters from a stream

A.8 The GRASS Problem-Solving Manual

transport.misc

- 0 Background
- 1 Power transmission line
- 2 Aircraft landing strip

trn.sites

- 0 No Data
- 1-20 Training areas within Fort Rushmore boundary

vegcover *[Vegetation cover classified from September, 1979, Landsat image.]*

- 0 No data
- 1 Irrigated Agriculture
Irrigated cropland and pasture.
Primarily herbaceous range, but contains some unimproved haylands (meadow hay).
- 2 Rangeland
Ponderosa-Lodgepole Pine and White Spruce.
- 3 Coniferous Forest
Quaking Aspen, Bur Oak, and Cottonwood.
- 4 Deciduous Forest
Mixture of coniferous and deciduous forest.
- 5 Mixed Forest
A greatly mixed class that includes Urban land, surface mines, exposed rock and soil, and smoke-covered areas.
- 6 Disturbed Land

Short Descriptions of Archaeological Sites in the Spearfish, South Dakota area.

Serial
No. Description

- 1 Signature Rock is a well-known landmark: a somewhat irregular 40 ft natural spire of igneous rock, overlooking a small meadow. Petroglyphs and pictographs (some in color); some individual elements, some grouped, others overlapping. Some graffiti in English, Spanish, and French. Age certain; authenticity of some elements is debatable (e.g., a scrawled sentence, "Jed Smith slep here" [sic]). Nominated for inclusion in the National Register by a local historical society.
- 2 Site consists of a natural outcropping of nodules of so-called "Minnelusa" chert; primary colors are red and purple. A few flakes and cores were observed; none collected. No diagnostic artifacts. Many such outcroppings of Minnelusa chert are known in the Black Hills; some are larger and much more extensively utilized. The site was judged ineligible for the National Register.
- 3 Site consists of the remains of three collapsed wooden frame and log structures. Rusty iron parts; trash of metal cans (hole in top); Euroamerican ceramics. According to the local residents, the site was once a way-station on the Spearfish-Western Stagecoach Line, and has been nominated to the National Register by a local historical society.
- 4 The Spearfish Creek site was excavated during the 1960's by faculty and students from a community college; the same group conducted a brief survey of the locality -- no other sites were identified. The site itself is situated on a low bluff overlooking Spearfish Creek. Remains of

Appendix Two

Note: The site data contained in this listing, like Camp Rushmore, are fictitious. They were created for teaching purposes only by Dr. William C. Smith, Department of Anthropology, Central Washington University. Although they are representative of the types of sites that might be found in the area, any correspondence between sites on this list and existing sites is purely coincidental.

A.10 The GRASS Problem-Solving Manual

two circular earth lodges were excavated, and trenches were cut through a low earthen embankment that formed a roughly rectangular or oval enclosure around the lodges. Several cache pits were described, some filled with trash; including fragments of incised and rim-indented pottery, and one fragment of catlinite or soapstone. Projectile points and fragments are of small, triangular, side-notched styles. A single radiocarbon date from a fire-hearth placed the occupation at about 1350 B.C.

- 5 Site I-90-39 was recorded during the survey prior to construction of the freeway, and determined to be eligible for the National Register. Excavation was carried out under the mitigation program. The site consists of small lithic and faunal scatters (with remains of bison, deer, antelope, and rabbit). Several milling stones (and fragments) were found, in close association with two fire hearths. Charcoal from these provided radiocarbon dates ranging between about 2200 and 3500 B.C. Projectile points of local chert, McKean type. Two (possibly three?) pithouse depressions; three storage (?) pits.
- 6 The Prairie Site was recorded during the I-90 survey, when an edge of the site was transected during construction of an access road. Preliminary testing showed that the remainder of the site would be undisturbed by further construction, and suggested that the site may represent a village of the Plains Woodland period. Testing encountered several probable storage pits, three probable postmolds suggesting pole-and-mat shelter, and midden areas of lithics, faunal remains, and pottery (undecorated and cord impressed). The site has been nominated to the National Register and recommended for full-scale excavation.
- 7 Site appears to have been a Paleoindian bison kill site; discovered eroding from the road-cut; vandalized prior to scientific investigation.

- 8 During construction of I-90, human remains were identified in a bulldozer cut. These probably represented the remains of two, possibly three burials. The remains were vandalized before they could be studied scientifically. It is rumored that local relic hunters recovered several McKean points, and possibly other artifacts.
- 9 Site consists of a relatively large scatter of local chert; some flakes and cores; no diagnostic lithics or faunal material observed during I-90 survey. The site was subsequently transected by the construction of the freeway. Determined ineligible for the National Register; no further investigation recommended.
- 10 The site is located in a grassy meadow overlooking the upper portion of Slaughterhouse Gulch. Over the years, relic hunters using metal detectors have reported finding metal fragments, deformed bullets, a few horseshoes in the turf of the meadow. An iron arrowhead-shaped projectile point is reported to have come from the site. According to a local legend, this is a battlefield where a skirmish was fought by troops of the U.S. Cavalry Expedition of 1874, led by General George Custer; however, there is no historical evidence that the Custer expedition passed through this immediate area.
- 11 Site consists of four (or five) "tipi rings" (irregular circles of small stone boulders, presumably used as anchor stones for tipis). Reported in the 1960's by students and faculty from a community college archaeology field class. Somewhat disturbed by recent land use.
- 12 Situated on a ridge north of Elkhorn Peak, the site consists of 15 (17?) small cairns, each made of several small rough boulders. Slightly farther up the ridge there is a large, irregular burned area, some 5-7 meters across, with charcoal and fire-cracked rock.

A.12 The GRASS Problem-Solving Manual

- 13 Site consists of a sparse natural outcrop of local chert; a few flakes and cores were observed, but none collected. The site has no depth of deposit. Judged ineligible; no mitigation recommended.
- 14 Site consists of a relatively large natural outcropping of Minnelusa chert, many flakes and cores. Some broken preforms. Two complete McKean projectile points, and three probable point fragments.
- 15 Site is recorded during survey for construction of I-90; excavated as part of the mitigation program; determined eligible for the National Register. Excavation revealed the remains of four or five bison; knife fragments and projectile point fragments (Angostura style) of Black Hills quartzite. Analysis of some faunal specimens suggested a late summer occupation, radiocarbon dated to about 7000 B.C.
- 16 Site consists of the collapsing remains of a small frame house; paired inside with yellowed newsprint; several dates from the mid-1930's; broken bottles and jars (clear glass, brown glass); fragments of polychrome (flower patterned) and plain ceramics; some pieces of rusting iron and tin cans. Vandalized by gunshot and by removal of planking. Deemed ineligible for National Register due to recent date and poor condition.
- 17 The Ridge Site was reported by a crew member from the I-90 survey, who hiked up the unnamed ridge between Polo Creek and Miller Creek, on his free time. The site consists of an earthen mound, about 6 meters in diameter, containing the somewhat disturbed burials of several individuals; shards of thick, undecorated pottery and cord-impressed pottery; several large side-notched and corner-notched projectile points and point fragments; burials (according to local relic hunters) were flexed. About 60 meters to the NE there is an irregular

depression of similar size, with a thin scatter of pottery shards (possibly a second mound, more fully vandalized?).

- 18 Mine shaft; several prospect pits; tailings; rusting iron parts; Euroamerican ceramics; trash; hewn and sawed timbers; foundation stones.
- 19 Site consists of several small elements of rock art (petroglyphs) on the face of a boulder, located to one side of a saddle between the headwaters of the Sandy Creek and an unnamed gully leading down to Boulder Creek. Figures of deer and mountain sheep (?) predominate.
- 20 Site consists of a large cairn or pile of rough boulders (each about 1 ft diameter); 4 ft across, by about 4 ft high. Reported by a forest ranger.
- 21 The site consists of several dozen "tipi rings" (irregular stone circles, 12 to 25 ft diameter, possibly used as anchor stones for tipis), some overlapping, extending along the flats overlooking the north bank of Whitewood Creek.
- 22 The site was reported by a local rancher (and former relic hunter), Bob Miller. Consisting of a rather thin but extensive scatter of lithics, animal bone, and pottery shards, the site is located on a narrow terrace just above Miller Creek, on the Miller Ranch. The landowner, in past years, has collected artifacts from the site (including McKean points and cord-impressed pottery) At present, he is protecting the site from further vandalism. Extensive testing has been recommended, to determine whether excavation is warranted.
- 23 Site was not detected prior to initiation of logging activity, but was

A.14 The GRASS Problem-Solving Manual

noted by a monitoring crew. Appears to have been a natural outcropping of chert. No flakes or cores noted (apart from a few that appeared to have been very recently fractured). No diagnostic artifacts.

- 24 The site was reported to a survey group of students and faculty from a community college, who visited the area in the 1960's. Reported by a local rancher, who had noticed artifacts eroding from the cutbank of a small tributary of Spearfish Creek. The college group collected small lithics, pottery fragments, (plain and cord-impressed pottery), and noted the presence of mussel shell and fish vertebrae. Since the site was overlain by a substantial deposit of alluvial/colluvial material, no testing or excavation was attempted.

- 25 Site consists of a sparse outcrop of local chert, of rather low quality. A few flakes and cores were noted, but no diagnostic artifacts.

Definitions for Category Names Used in Following Tables:

id = Number assigned in sites file.	e = UTM Easting.
name = Name by which site is known.	n = UTM Northing
project = Survey project during which site was recorded.	
state = Smithsonian trinomial (e. g. 45KT101).	
field = Temporary number assigned during field survey.	
disturbance = Whether caused by construction, vandalism, erosion, etc.	
status = Recorded, tested, or excavated.	
eligibility = Eligibility for National Register.	
type = Historic or prehistoric.	size = Surface area in square meters
date = As determined by C ₁₄ dating.	quad = USGS topographic quad name.
period = Relative dating to cultural/historical period.	
features = Such things as cairns, house-pits, storage pits, burials, tipi rings, etc.	
artifacts = Diagnostic materials such as projectile point types, pottery types, etc.	

Note: MV = missing value; NA = not applicable

Appendix Two, TABLE I.
Archaeological Sites in the Spearfish, SD, Area: Physical Characteristics

id	name	features	diag
1	Signature Rock	pictographs, petroglyphs, graffiti	none
2	No Name	lithic scatter	none
3	Canyon Station	frame bldgs, log bldgs, midden	iron parts, metal cans, glazed shards
4	Spearfish Creek	circular housepits, enclosing embankment, pits, midden, hearths	incised, rim-indented pottery; soapstone; triangular, side-notched points
5	No Name	midden, hearths, housepits, storage pits	McKean points
6	Prairie Site	storage pits, post molds, midden	undecorated pottery
7	Jensen Pass Site	scatter (lithic, faunal)	Angostura points
8	No Name	burials	McKean points
9	No Name	lithic scatter	none
10	Slaughterhouse Gulch	none	bullets, iron fragments
11	No Name	tipi rings	none
12	Elkhorn Peak	hearth, rock cairns	none
13	No Name	lithic scatter	none
14	No Name	lithic scatter	McKean points (& fragments)
15	No Name	scatter (lithic, faunal)	Angostura points
16	Boulder Creek Cabin	cabin	iron, recent ceramics
17	Ridge	burial mound	pottery (plain, cord-impressed), points (corner-notched, side-notched)
18	Cole Creek Mine	mine shaft, prospect pits, tailings, stone foundations	iron parts, timbers, Euro-American ceramics
19	No Name	petroglyphs	none
20	No Name	rock cairn	none
21	Whitewood Flats	tipi rings	lithics, iron
22	Bob Müller	scatter (lithic, faunal, ceramic)	pottery (cord-impressed), McKean points
23	No Name	lithic scatter	none
24	Hanson Ranch	MV	pottery (plain, cord-impressed), lithics, faunal
25	No Name	lithic scatter	none

A.16 The GRASS Problem-Solving Manual

Appendix Two, TABLE II.
Archaeological Sites in the Spearfish, SD, Area: Locations and Status

id	name	e	n	status	disturb	elig
1	Signature Rock	593493	4914730	recorded	vandalized	nominated
2	No Name	591950	4923000	recorded	none	ineligible
3	Canyon Station	589860	4922000	recorded	vandalized	nominated
4	Spearfish Creek	590400	4922820	excavated	vandalism	nominated
5	No Name	593549	4925500	excavated	none	eligible
6	Prairie Site	600375	4925235	reported	none	nominated
7	Jensen Pass Site	606635	4920773	recorded	vandalism	MV
8	No Name	595755	4925300	recorded	destroyed (construction, vandalism)	MV
9	No Name	601000	4926310	recorded	construction	ineligible
10	Slaughterhouse Gulch	602550	4917370	reported	construction, vandalism	MV
11	No Name	591635	4924340	reported	construction, cultivation	MV
12	Elkhorn Peak	603000	4925250	reported	none	MV
13	No Name	592100	4921200	reported	none	ineligible
14	No Name	592600	4922000	recorded	none	eligible
15	No Name	604194	4925980	excavated	none	eligible
16	Boulder Creek Cabin	608200	4915900	reported	vandalism	ineligible
17	Ridge	601400	4925450	reported	vandalism	MV
18	Cole Creek Mine	591000	4916600	recorded	MV	MV
19	No Name	607150	4916650	reported	none	eligible
20	No Name	593690	4914479	recorded	none	MV
21	Whitewood Flats	608355	4926490	reported	vandalism, cattle, erosion	MV
22	Bob Miller	597945	4918950	reported	vandalism	MV
23	No Name	607159	4917000	reported	logging	ineligible
24	Hanson Ranch	591583	4925280	reported	erosion	MV
25	No Name	602580	4918480	reported	none	ineligible

Appendix Two, TABLE III.
Archaeological Sites in the Spearfish, SD, Area: Administrative Data

id	name	type	project	state	field	quad
1	Signature Rock	p, h	NA	MV	NA	Spearfish
2	No Name	p	Timbersale Survey	MV	T-3	Spearfish
3	Canyon Station	h	NA	MV	NA	Spearfish
4	Spearfish Creek	p	College Survey	MV	C-3	Spearfish
5	No Name	p	I-90 Survey	MV	I-90-39	Spearfish
6	Prairie Site	p	I-90 Survey	MV	I-90-44	Deadwood
7	Jensen Pass Site	p	NA	MV	NA	Deadwood
8	No Name	p	I-90 Survey	MV	I-90-40	Spearfish
9	No Name	MV	I-90 Survey	MV	I-90-42	Deadwood
10	Slaughterhouse Gulch	h	NA	MV	NA	Deadwood
11	No Name	p, ph	College Survey	MV	C-2	Spearfish
12	Elkhorn Peak	MV	NA	MV	NA	Deadwood
13	No Name	p	Timbersale Survey	MV	T-9	Spearfish
14	No Name	p	Timbersale Survey	MV	T-4	Spearfish
15	No Name	p	I-90 Survey	MV	I-90-43	Deadwood
16	Boulder Creek Cabin	h	Timbersale Survey	MV	T-29	Deadwood
17	Ridge	p	NA	MV	NA	Deadwood
18	Cole Creek Mine	h	NA	MV	NA	Spearfish
19	No Name	p	Timbersale Survey	MV	T-31	Deadwood
20	No Name	MV	NA	MV	NA	Spearfish
21	Whitewood Flats	p, ph	NA	MV	NA	Deadwood
22	Bob Miller	p	NA	MV	NA	Deadwood
23	No Name	p	Timbersale Survey	MV	T-30	Deadwood
24	Hanson Ranch	p	College Survey	MV	C-1	Spearfish
25	No Name	p	Timbersale Survey	MV	T-17	Deadwood

A.18 The GRASS Problem-Solving Manual

Appendix Two, TABLE IV.
Archaeological Sites in the Spearfish, SD, Area: Chronological Data

id	name	type	period	date	size
1	Signature Rock	p, h	MV	0	17
2	No Name	p	MV	0	2625
3	Canyon Station	h	MV	0	2600
4	Spearfish Creek	p	Plains Village	600	15000
5	No Name	p	Plains Archaic	5500	2100
6	Prairie Site	p	Plains Woodland	0	38400
7	Jensen Pass Site	p	Paleoindian	0	0
8	No Name	p	Plains Archaic	0	0
9	No Name	MV	MV	0	21875
10	Slaughterhouse Gulch	h	Military	0	0
11	No Name	p, ph	MV	0	8400
12	Elkhorn Peak	MV	MV	0	1200
13	No Name	p	MV	0	3600
14	No Name	p	Plains Archaic	0	5625
15	No Name	p	Paleoindian	8900	312
16	Boulder Creek Cabin	h	Recent Historic	0	1350
17	Ridge	p	Plains Woodland	0	4950
18	Cole Creek Mine	h	Mining	0	8450
19	No Name	p	MV	0	5
20	No Name	MV	MV	0	6
21	Whitewood Flats	p, ph	MV	0	20000
22	Bob Miller	p	MV	0	0
23	No Name	p	MV	0	700
24	Hanson Ranch	p	Plains Woodland	0	0
25	No Name	p	MV	0	2625

Keystroke Guide to Procedures: Problems 1 through 6.

Appendix Three

Problem Situation No. 1

METHOD 1

1. **Dcell** **trn.sites**
- 2a. **mask**
 - > 2 (identify new mask)
 - > **trn.sites** (name of data layer to be used for mask)
 - > identify categories to be included in mask:
(set all categories except 0 to 1)
- 2b. **Gcopy cell MASK** **rushmore**
3. **Dcell** **rushmore** (or use **display**)
4. **Drect** **roads** (or use **display**)

METHOD 2

1. Same as Step 1, Method 1
2. **Gmapcalc** **rushmore = trn.sites/trn.sites**
- 3-5. Same as Steps 3-5, Method 1

METHOD 3

1. Same as Method 1
- 2a. **reclass**
 - > **trn.sites** (name of map to be reclassified)
 - > **rushmore** (name of new map)
 - > 0 or 1 (set initial class values)
 - > ...(reclass table, 0 becomes 0, else 1)
- 3-5. Same as Steps 3-5, Method 1

Note: This list contains a step-by-step, stroke-by-stroke listing of the procedures used on problems 1 and 6 of this manual. It is meant to be used when or if you should get "stuck" while working through the problems. What is important here is not the list but the pattern of the command entries you must make in solving a problem. All problems require similar patterns of keyboard entry, but obviously the precise sequence will vary from tool to tool and command to command.

The order of procedure is that used in GRASS 3.0. It may change for subsequent versions.

A.20 The GRASS Problem-Solving Manual

Problem Situation No. 2

1. **Gmapcalc MASK = tm.sites/tm.sites**
2. **display**, use mouse to:
 - > **display** cell file streams
 - > **color-interact**
 - > **"h"** (highlight categories)
 - > **"Q"** (quit display)
3. **distance**
 - > **streams** (existing file)
 - > **strms.dist**
 - > **2** (put 1 beside categories from which distances will be calculated)
 - > ...distance table (set distance category 1 to 1 (to 100 meters); set category 2 to 2 (to 200 meters)
4. **Decreen**
5. **Dcell strms.dist** (will only show stream buffer zones located inside the mask)

Problem Situation No. 3

1. **Gmapcalc MASK = tm.sites/tm.sites**
2. **reclass**
 - > **vegcover** (existing map. to be reclassified)
 - > **woodland** (new map name)
 - > set categories 3, 4, and 5 to 1; other categories set automatically to 0
3. **distance**
 - > **bugsites** (existing map)
 - > **beetle.zones** (new map name)
 - > calculate distance from category 2 by putting 1 beside it.
 - > enter 5 beside distance table category 1 (i.e., to 500 meters)
 - > use **from_cell** or **to_cell** method
4. **Gmapcalc**
 - > **beetle.dmg** = 'if (beetle.zones-1,0,1,0)'
 - > **wood.mvr** = 'if (beetle.dmg * woodland, woodland - beetle.dmg, woodland)'

Problem Situation No. 4

1. `Dcell mss.image`
2. `neighbors` .

> `mss.image` (existing file)

- Warns that current window has resolution different from that of map layer.

Problem Situation No. 5

1. `mask`

> 2 (identify new mask)
 > `rm.sites` (existing map)
 > (set categories 3-9 to 1, others become 0)
 > `exit mask`

2. `distance`

> `streams` (existing map)
 > `strms.dist` (new map name)
 > (set category 2 to 1, others become 0)
 > (set distance category 1 to 2 (200 meters))

3. `distance`

> `roads` (existing map)
 > `rds.dist` (new map name)
 > (set category 4 [trails] to 1, others become 0)
 > (set distance category 1 to 1 (100 meters))
 > use `to_cell` or `from_cell` method

4. `Gmapcalc`

> `corridors` = 'if (strms.dls == 1 || rds.dist == 1)'
 > `encamp.zones` = `abs (corridors - 1)`

A.22 The GRASS Problem-Solving Manual

Problem Situation No. 6

1. Gmapcalc
 - > MASK = 'if (tm.sites || owner == 2, 1)'
2. Gmapcalc
 - > slope.dens = 'if (slope == 7 && density == 4)'
3. distance
 - > bugsites (existing map)
 - > bug.zones (new map name)
 - > (calculate distances from bugsites category 2)
 - > (set distance category 1 to 5 (500 meters))
 - > to_cell or from_cell
4. Gmapcalc
 - > bugs.dist = 'if (bug.zones == 1)'
5. weight
 - > choose vegcover slope.dens bugs.dist
 - > assign vegcover 3 3
 - > assign vegcover 4 1
 - > assign vegcover 5 2
 - > assign slope.dens 1 1
 - > assign bugs.dist 1 1
 - > save analysis
 - > execute (save results in cell file fire.danger)
6. reclass
 - > fire.danger (existing map)
 - > fire.potential (new map name)
 - > 0 or 1 (initialize category values)
 - > (reclass old categories 1-2 to 1)
 - > (reclass old categories 3-4 to 2)
 - > (reclass old category 5 to 3)

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